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GRAND RIVER BASIN WATER MANAGEMENT STUDY TECHNICAL REPORT SERIES

FLOOD DAMAGES

IN THE

GRAND RIVER BASIN

TECHNICAL REPORT No. 39

Ontario

GRAND RIVER IMPLEMENTATION COMMITTEE

GRAND RIVER BASIN WATER MANAGEMENT STUDY

GRAND RIVER STUDY TEAM

FLOOD DAMAGES

IN THE GRAND RIVER BASIN

Technical Report No. 39

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FOREWARD

This report is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The project described herein was undertaken by the Grand River Hydrology Sub-committee at the request of the Grand River Implementation Committee.

The material contained in this report is primarily technical support information and in itself does not necessarily constitute policy or management practices. Interpretation and evaluation of the data and findings, in most cases, cannot be based solely on this report but should be analysed in light of other reports produced within the comprehensive framework of the overall study. Questions with respect to the contents of this report should be directed to the Co-ordinator of the Grand River Basin Water Management Study, Grand River Conservation Authority, 400 Clyde Road, P.O. Box 729, CAMBRIDGE, Ontario. N1R 5W6.

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TABLE OF CONTENTS

PAGE

FOREWARD i
TABLE OF CONTENTS ii
LIST OF TABLES iii
LIST OF FIGURES iv
SUMMARY AND RECOMMENDATIONS v

1.0 INTRODUCTION.....1
2.0 FLOODPRONE COMMUNITIES IN THE GRAND RIVER BASIN 3
3.0 FLOOD CONTROL IN THE GRAND RIVER BASIN 3
4.0 FLOOD DAMAGES IN THE GRAND RIVER BASIN - METHODOLOGY 7
4.1 Establishing the Flow-Frequency Relationship 7
4.2 Establishing the Flow-Damage Relationship 10
4.2.1 Stage-Flow Relationship 10
4.2.2 Stage-Damage Relationship 10
5.0 FLOOD DAMAGES IN THE GRAND RIVER BASIN - RESULTS 13
5.1 Grand Valley 16
5.2 Elora 18
5.3 Kitchener (Bridgeport) 20
5.4 Guelph 22
5.5 Cambridge (Hespeler) 24
5.6 Cambridge (Preston) 26
5.7 Cambridge (Galt) 28
5.8 Paris 30
5.9 New Hamburg 32
5.10 Plattsville 34
5.11 Ayr 36
5.12 Brantford 38
5.13 Caledonia 40
5.14 Dunnville 42

REFERENCES 44

APPENDIX A - Regulated Flow-Frequency Curves A1
APPENDIX B - Regional Flows B1
APPENDIX C - Unit Stage-Damage Relationships C1

LIST OF TABLES

PAGE

Table 1 Floodprone Communities in the Grand River Basin 3
Table 2 Proposed Flood Damage Reduction Alternatives in The Grand River Basin 5
Table 3 Unit Stage-Damage Relationship (structure+content) for Residential Frame or Brick Homes with Basements 11
Table 4 Unit Stage-Damage Relationship (structure+content) for Commercial, Industrial and Institutional Structures 11
Table 5 Indirect Damages as a Ratio of Direct Damages 12
Table 6 Average Annual Damages for 6 Major Floodprone Communities for Existing and Proposed Flood Damage Reduction Alternatives 14
Table 7 Floodplain Inventory and Flood Damages for 14 Floodprone Communities 15
Table 8 Grand Valley Flow-Frequency-Damage Table 17
Table 9 Elora Flow-Frequency-Damage Table 19
Table 10 Bridgeport Flow-Frequency-Damage Table 21
Table 11 Guelph Flow-Frequency-Damage Table 23
Table 12 Hespeler Flow-Frequency-Damage Table 25
Table 13 Preston Flow-Frequency-Damage Table 27
Table 14 Galt Flow-Frequency-Damage Table 29
Table 15 Paris Flow-Frequency-Damage Table 31
Table 16 New hamburg Flow-Frequency-Damage Table 33
Table 17 Plattsville Flow-Frequency-Damage Table 35
Table 18 Ayr Flow-Frequency-Damage Table 37
Table 19 Brantford Flow-Frequency-Damage Table 39
Table 20 Caledonia Flow-Frequency-Damage Table 41
Table 21 Dunnville Flow-Frequency-Damage Table 43
Table B-1 Average Annual Damages at Galt and Brantford for Different Return Periods of the Regional Flow B1
Table B-2 Summary of Estimated Maximum Flows for Metro Toronto Watersheds (from ref. 3) B2
Table B-3 Regional Flows used in Grand River Basin Flood Damage Analysis B4
Table C-1 Unit Stage-Damage Relationship (structure+content) for Frame or Brick Homes with Basements ($1979) (modified ACRES) C2
Table C-2 FIA Depth-Damage Relationship (structure+content) for Residential Structures C2
Table C-3 Comparison of Observed 1974 Residential Flood Damages at Bridgeport and Paris with Estimated Damages C4
Table C-4 Residential Unit Stage-Damage Relationships Glen Gowan Dam Study (from ref. 20) C4
Table C-5 Total Flood Damages at Galt - %Contribution by Residential, Commercial, Industrial, Institutional and Public Damages C5
Table C-6 Total Flood Damages at Brantford - %Contribution by Residential, Commercial, Industrial, Institutional and Public Damages C5

LIST OF FIGURES

PAGE

Figure 1 Location of Floodprone Communities in the Grand River Basin 4
Figure 2 Location of Proposed Flood Damage Reduction Alternatives in the Grand River Basin 6
Figure 3 Components of the Frequency-Damage Curve 8
Figure 4 Extrapolation of Regulated Flows to greater than the 100 Year Flow 9
Figure 5 Grand Valley Frequency-Damage Curve 16
Figure 6 Grand Valley Flow-Damage Curve 17
Figure 7 Elora Frequency-Damage Curve 18
Figure 8 Elora Flow-Damage Curve 19
Figure 9 Bridgeport Frequency-Damage Curve 20
Figure 10 Bridgeport Flow-Damage Curve 21
Figure 11 Guelph Frequency-Damage Curve 22
Figure 12 Guelph Flow-Damage Curve 23
Figure 13 Hespeler Frequency-Damage Curve 24
Figure 14 Hespeler Flow-Damage Curve 25
Figure 15 Preston Frequency-Damage Curve 26
Figure 16 Preston Flow-Damage Curve 27
Figure 17 Galt Frequency-Damage Curve 28
Figure 18 Galt Flow-Damage Curve 29
Figure 19 Paris Frequency-Damage Curve 30
Figure 20 Paris Flow-Damage Curve 31
Figure 21 New Hamburg Frequency-Damage Curve 32
Figure 22 New Hamburg Flow-Damage Curve 33
Figure 23 Plattsville Frequency-Damage Curve 34
Figure 24 Plattsville Flow-Damage Curve 35
Figure 25 Ayr Frequency-Damage Curve 36
Figure 26 Ayr Flow-Damage Curve 37
Figure 27 Brantford Frequency-Damage Curve 38
Figure 28 Brantford Flow-Damage Curve 39
Figure 29 Caledonia Frequency-Damage Curve 40
Figure 30 Caledonia Flow-Damage Curve 41
Figure 31 Dunnville Frequency-Damage Curve 42
Figure 32 Dunnville Flow-Damage Curve 43
Figure A-1 Flood Peak Reduction at Cambridge (Galt) for Various Reservoir Storage Capacities (Belwood and Conestogo Reservoirs) A2
Figure A-2 Flood Frequency Curves at Cambridge (Galt) for Various Reservoir Storage Capacities (Belwood and Conestogo Reservoirs) A3
Figure B-1 Peak Flow Recurrence Intervals for Etobicoke Creek at Summerville (from ref. 15) B3

SUMMARY

Fourteen communities in the Grand River Basin have urban flood damages that are large and/or frequent enough to be considered significant.

These communities are: Grand Valley, Elora, Kitchener(Bridgeport), Guelph, Cambridge(Hespeler), Cambridge(Preston), Cambridge(Galt) , Paris, New Hamburg, Plattsville, Ayr, Brantford, Haldimand(Caledonia) and Dunnville.

The concept of Average Annual Damage is used to provide one number that weights the magnitude and frequency of expected flood damages at a given site. This number may then be used in cost/benefit analysis of flood damage reduction alternatives.

Total Average Annual Damages for the six major floodprone centres in the basin (Cambridge, Paris, New hamburg, Brantford, Caledonia and Dunnville) for the existing reservoir and dyking systems are $985,00 (1979). This includes direct and indirect damages to residential, commercial, industrial and institutional structures and contents.

Proposed reservoir and dyking systems can reduce the Average Annual Damages of these communities by over 90%.

RECOMMENDATIONS

1. Future studies of urban flood damages in the Grand River Basin should concentrate effort in assessing industrial flood damages and develop industrial damage curves for major industrial sites. Industrial damages contributed to over 60% of the total flood damages at Cambridge(Galt) and Brantford.

2. Future studies on flow-frequency should attempt to verify the frequency of the Regional Flow.

3. The Regional Flood should be reviewed for all fourteen floodporne communities in the Grand River Basin; especially for those on the Nith and Speed Rivers.

1.0 INTRODUCTION

Technical Report No. 39 is one of a series of five technical reports dealing with flood flows and flood damages in the Grand River basin. These reports are:

Technical Report	No. 35	Flow Frequency Analysis
	No. 36	Design Floods
	No. 37	Application Of The HEC-5 Model
	No. 38	Reservoir Operations
	No. 39	Flood Damages

The overall objective of the flood flows study is to produce stage-flow-frequency-damage relationships at all flood prone urban centres:

a) under natural conditions;
b) under regulation by the existing reservoir system, and as affected by existing dyke systems;
c) under regulation by proposed reservoirs, and as affected by proposed dyke and channel improvement schemes.

In order to satisfy this objective, several steps were undertaken:

In Technical Report No. 35:

1) the natural flood hydrograph was estimated for maximum annual spring freshet events at long-term gauge stations where flows are regulated by the existing reservoir system;

2) the flow-frequency relationship was established at:

   a) the long-term stations using the natural peak flows established in step 1.
   b) at long-term stations where flows have not been regulated.

In Technical Report No. 36:

3) the hydrological processes of the watershed were modelled; the 5, 10, 25, 50 and 100-year flood flows at all flood prone urban centres were obtained by simulating flood events whose peaks at stations with long-term record matched the natural flow-frequency relationship established in step 2.

In Technical Report No. 38:

4) the operation of the major reservoirs during high flow events was modelled; the effects of the reservoir systems, existing and proposed, on the 5, 10, 25, 50, and 100-year and the regional storm flood events were determined.

In Technical Report No. 39 (this report):

5) the frequency-damage relationships were estimated at each flood prone urban area for existing conditions and with proposed dyking and channel improvements in place. From these relationships, average annual damages were calculated.

In assessing structural flood damage reduction alternatives the concept of average annual damage (AAD) may be used. The lowering of AAD by either dyking, channelisation or flood control reservoirs would be a benefit attached to the alternative and an indication of the relative merit of the project.

For a given site, the AAD is defined as the area under the frequency-damage curve. That is: the damage for a given flow weighted by the frequency of that flow summed over the range of flows experienced at the site.

This report describes the methodology used in creating the flow-damage relationships for 14 floodprone communities in the Grand River basin as well as reporting the flow-frequency relationships at each site and the average annual damages from the resulting frequency-damage curves.

2.0 FLOODPRONE COMMUNITIES IN THE GRAND RIVER BASIN

A list of floodprone communities addressed in this report is given in Table 1 with their locations shown in Figure 1. The list includes 14 communities with reported damages as well as those with a potential for significant damages.

Not included in the list are the following communities: Drayton, Wallenstein, St. Jacobs, Hayesville, Hawkesville, Wolverton, Eden Mills, Rockwood and Haldimand (Cayuga). They too experience flood damages but the average annual damages were assumed to be negligible in comparison with those in Table 1.

Table 1 Floodprone Communities in the Grand River Basin

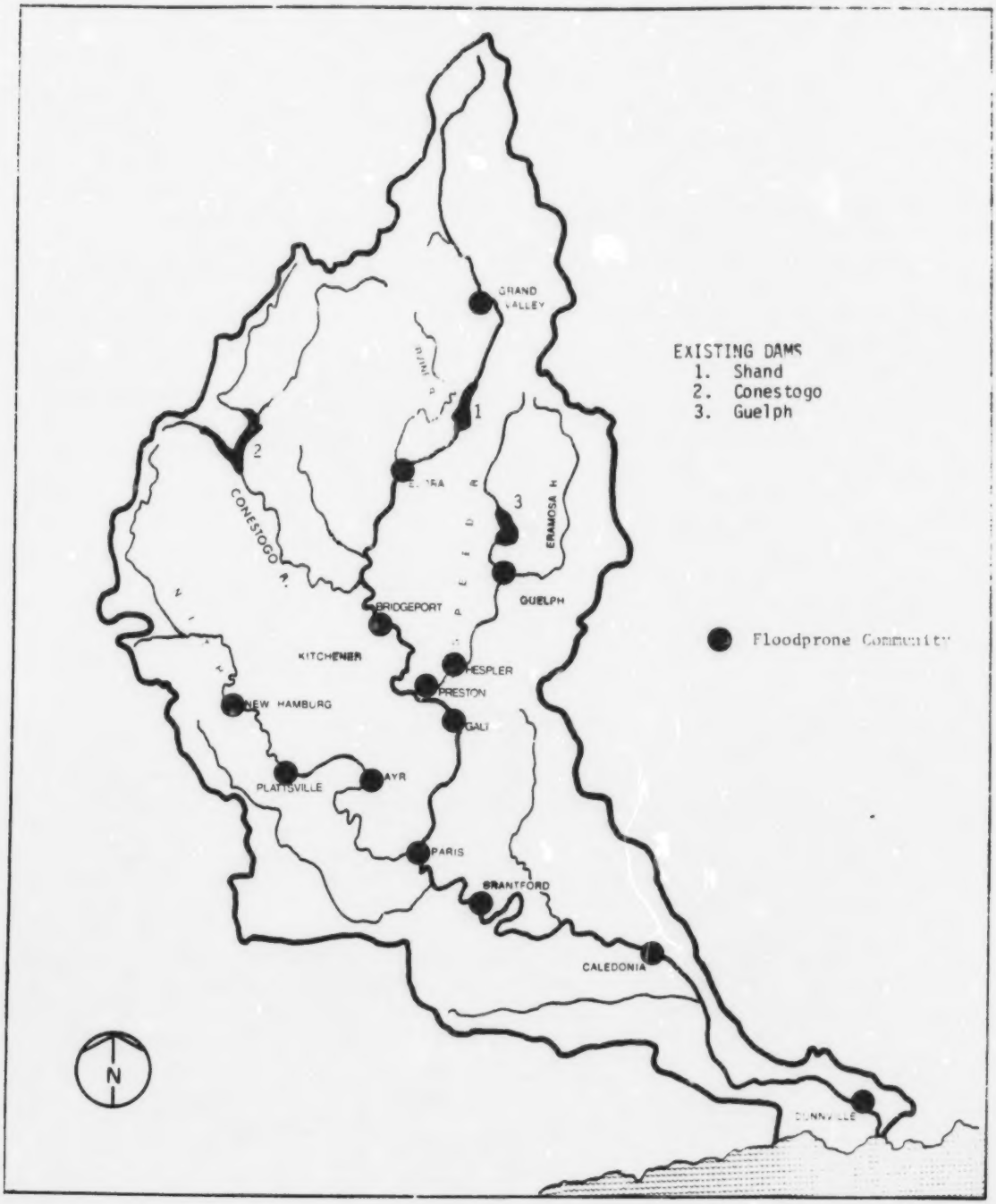
Community	River
Village of Grand Valley	Grand
Village of Elora	Grand
City of Kitchener (Bridgeport)	Grand
City of Guelph	Speed
City of Cambridge (Hespeler)	Speed
City of Cambridge (Preston)	Speed
City of Cambridge (Galt)	Grand
Town of Paris	Grand
Town of New Hamburg	Nith
Village of Plattsville	Nith
Village of Ayr	Nith
City of Brantford	Grand
Town of Haldimand (Caledonia)	Grand
Town of Dunnville	Grand

3.0 FLOOD CONTROL IN THE GRAND RIVER BASIN

Flood flows in the Grand River basin are currently controlled by three dams: the Shand Dam on the upper Grand River, the Conestogo Dam on the Conestogo River and the Guelph Dam on the Speed River as indicated in Figure 1 . In addition, flooding in Bridgeport, Guelph, Galt, Paris, New Hamburg, Brantford and Dunnville is lessened by the existing dyking systems.

Flood events usually occur during spring runoff (March - April). However, the potential exists for major flooding events to occur during the months of May and June when the reservoirs have the least flood storage available or during the hurricane season (July - October).

Figure 1 Location of Floodprone Communities in the Grand River Basin



While the existing dams and dyking systems provide a large degree of flood control for communities in the Grand River basin, significant flood damages still occur. The proposed structural flood damage reduction alternatives considered by the Grand River Basin Water Management Study are listed below in Table 2 and their locations are shown in Figure 2. These alternatives were based on previous flood damage reduction projects investigated by the GRCA and include:

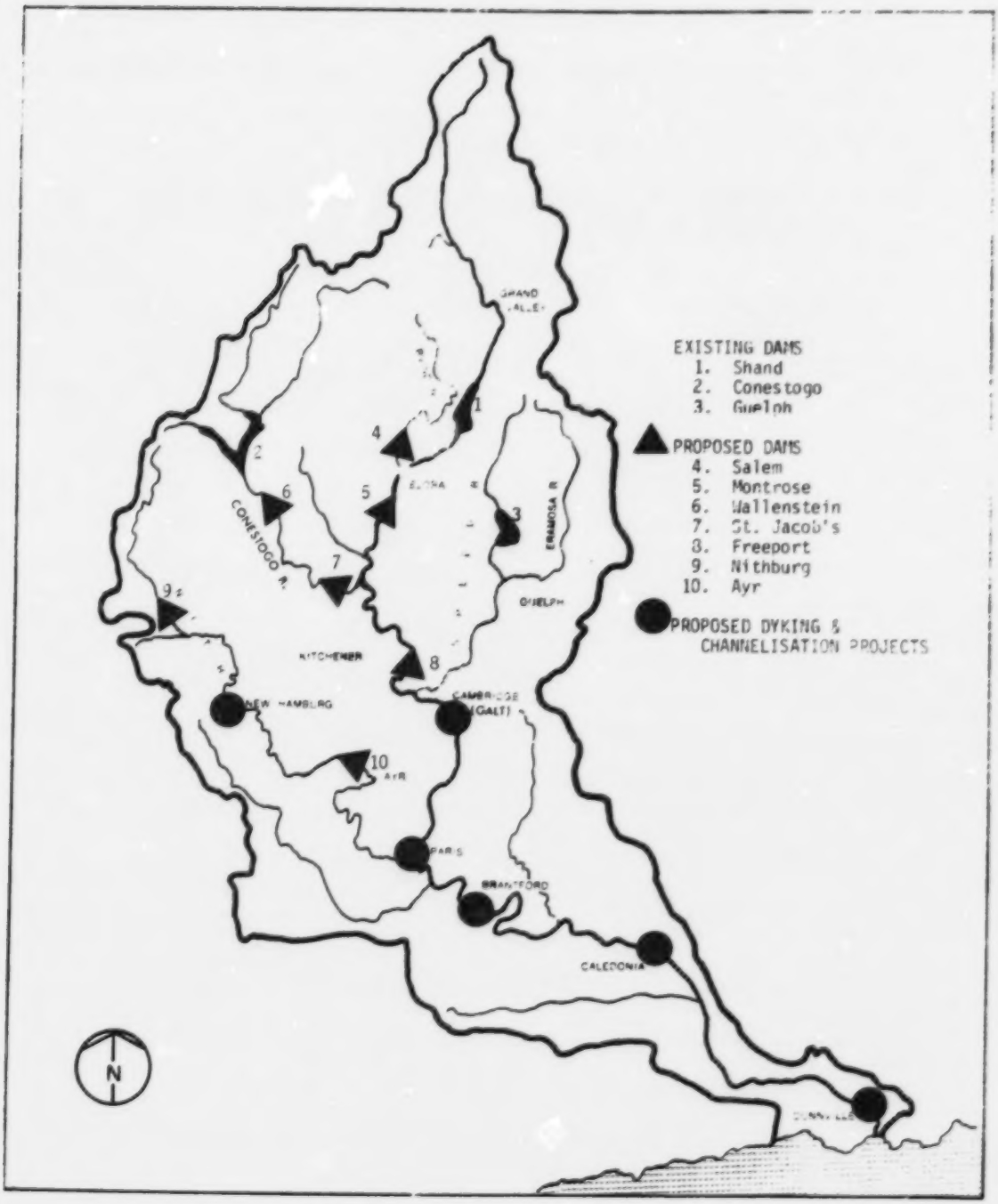
1) multi-purpose reservoirs for flood control, low flow augmentation and water supply
2) single-purpose reservoirs for flood control only
3) dyking and channelisation schemes

Table 2 Proposed Flood Damage Reduction Alternatives in the Grand River Basin

M - multi-purpose reservoir
S - single-purpose reservoir

Alternative		Maximum Flood Storage (acre-feet)	Minimum Flood storage (acre-feet)
1) EXISTING (Shand, Conestogo, Guelph)	(M)	120,000	8,000
1) Montrose Dam	(M)	66,000	20,000
2) Montrose Dam	(S)	20,000	20,000
3) St. Jacob's Dam	(S)	16,000	16,000
4) Salem Dam	(S)	11,000	11,000
5) Wallenstein Dam	(M)	16,000	8,000
6) Wallenstein Dam	(M)	16,000	8,000
Salem Dam	(S)	11,000	11,000
7) Wallenstein Dam	(M)	16,000	8,000
St. Jacob's Dam	(S)	16,000	16,000
Freeport Dam	(S)	12,000	12,000
Salem Dam	(S)	11,000	11,000
8) Nithburg Dam	(M)	24,000	15,000
9) Ayr Dam	(M)	80,000	60,000
10) Dyking and Channelisation			
11) Dyking and Channelisation (with Montrose Dam)		20,000	20,000

Figure 2 Location of Proposed Flood Damage Reduction Alternatives in the Grand River Basin



4.0 FLOOD DAMAGES IN THE GRAND RIVER BASIN - METHODOLOGY

Flood damages are reported in the form of average annual damages (AAD) in order to weight the magnitude of the damages at different flows by the expected frequency of occurrence of those flows. The AAD for a given community is simply the area under the frequency-damage curve for that community. Figure 3 shows how the frequency-damage relationship is constructed from the stage-flow, stage-damage, flow frequency and flow-damage relationship at a community. Each component is dealt with in in the following sections.

4.1 Establishing the Flow-Frequency Relationship

The natural flow-frequency relationships (without the effects of the existing reservoir system) for the 5, 10, 25, 50 and 100 year flood events for each of the 14 floodprone communities were established in Technical Report #36 - Design Floods. The frequency (return period) of flows greater than the 100 year were assumed to be on the curve resulting from straightline extrapolation of the 5 to 100 year flows.

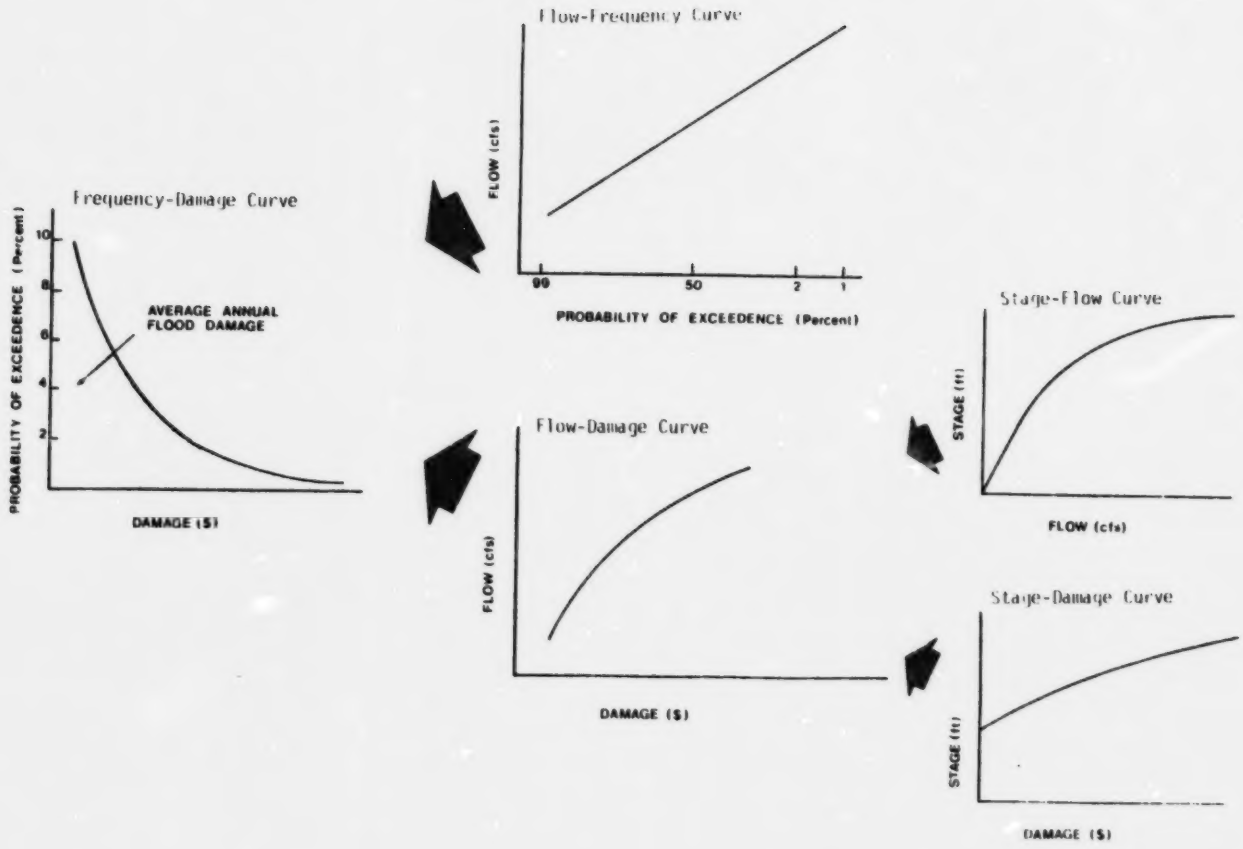
The natural flow-frequency curves were used in assessing damages in communities unaffected by either the existing reservoir system or by any proposed reservoir system.

For those areas subject to regulation, existing or proposed, the regulated flow frequency curve was used. The regulated flow-frequency relationship was established by routing the natural or inflow flood hydrographs through the various reservoirs in the system. Routing was carried out using the HEC-5 reservoir simulation model and the existing GRCA reservoir operation policy. The resulting flow-frequency curve would depend upon the amount of reservoir flood storage available at the beginning of the routing process. In fact, a family of regulated flow frequency curves for each downstream community could be produced for different reservoir flood storage capacities (Ref. Appendix A).

The effect of different amounts of available reservoir flood storage upon downstream flood peaks at Cambridge and Brantford was examined. It was found that there was no difference in flood peak reduction for flood storages varying from 20% of available flood storage (April 1 existing operating policy) to 90% of available flood storage (March 1 existing operating policy) (Ref. Appendix A).This indicates that flood peak reductions are insensitive to the amount of reservoir flood storage available at the start of the flood period. It also indicates that a major component of downstream flood peaks is the uncontrolled local flows between the major dams and the flood prone communities.

Because of this insensitivity to available reservoir flood storage, a single reservoir storage capacity was selected to use in routing all inflows up to the 100 year event through the system. This resulted in a single regulated flow-frequency curve for each downstream community affected by regulation. The reservoir storage capacity selected was the April 1st existing operating conditions as defined by the existing GRCA reservoir operation policy. April 1 operating conditions specify that 20% of the total flood storage be made available for flood control.

Figure 3 Components of the Frequency-Damage Curve



Initially, regulated flows greater than the 100 year were assumed from the straightline extrapolation of the 5 to 100 year regulated flows. However, the Regional Flood did not fall on this curve with any reasonable return period as the curve only reflected the recurrence of spring freshet events. The high return period events (greater than 100 year) are probably dominated by summer and fall tropical storms and, in order to reflect their significant impact on flood damages, the Regional flood was fixed at a 500 year return period (Ref Appendix B).

The Regional Flood is defined as the flow resulting from the Regional Storm centered above the point of interest, reduced by a reservoir system at October 1st operating levels - 70% of reservoir flood storage available.

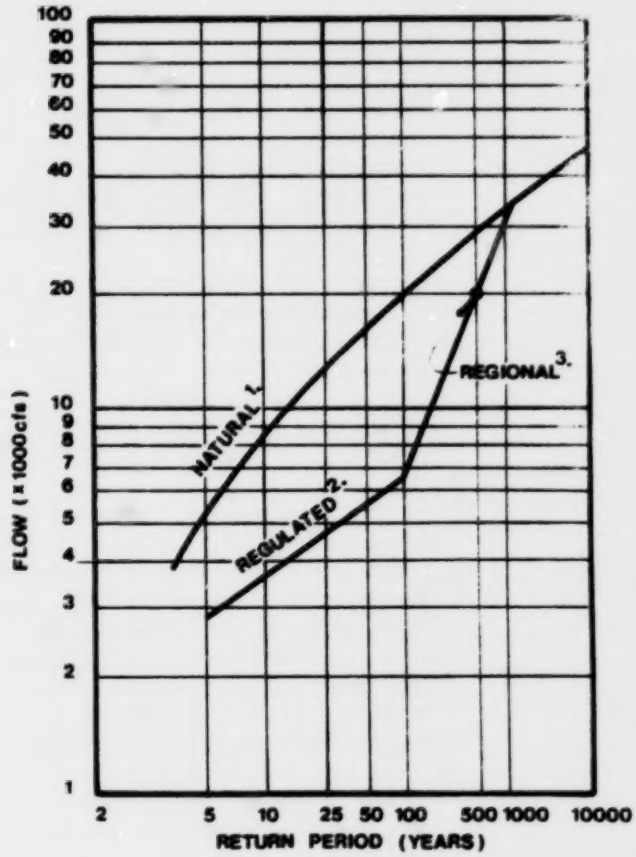
Figure 4 illustrates the above concept of extrapolation beyond the 100 year event.

Figure 4 Extrapolation of Regulated Flows to greater than the 100 Year Return Period

1. Derived from rainfall-runoff model (FLOOD2)

2. Derived from reservoir operations model (HEC-5)

3. Assumed 500 year return period. Flow established by previous GRCA study or FLOOD2/HEC-5 modelling.



4.2 Establishing the Flow-Damage Relationship

It may be possible to construct the flow-damage relationship from historical records alone but this is generally not done as damage records are incomplete and the buildings on the floodplain and their use change over the years. Instead, a synthetic flow-damage curve was constructed using unit damage curves applied to each structure in the floodplain. This creates a stage-damage curve which combined with a stage-flow curve produces a flow damage curve.

4.2.1 Stage-Flow Relationship

For each community a water surface profile was established for a range of flows from channel capacity to the regional flow. The computer model HEC-2, which incorporates the Standard Step Method for backwater calculations, was applied to surveyed cross-sections to arrive at the required profiles. The profiles were then used to assess the depth of flooding of structures on the floodplain over the range of flows.

4.2.2 Stage-Damage Relationship

Flood damages may be divided into three categories: direct, indirect and intangible.

Direct damages include damage to structures and their contents and physical damage to such public facilities as roads, bridges, and telecommunication systems. They are commonly classified as residential, commercial, industrial, institutional and public damages (institutional damages include damages to churches, clubs, and public buildings while public damages refer to the costs incurred in restoring transportation, communication and other public services).

Indirect damages include costs incurred due to loss of transportation and communication facilities, loss of commercial sales and industrial production, loss of employee wages and costs associated with flood warning and flood fighting.

Intangible damages include loss of life and reduced feelings of security in floodplain residents.

In the Grand River Basin Water Management Study unit-stage- damage curves were used to assess the direct damages that would occur to a given structure and it's contents for a given depth of flooding. Unit damages were assessed for residential, commmercial, industrial and institutional structures and contents. Indirect damages were assessed as a per cent of direct damages and public damages were assessed as a per cent of the total of direct and indirect damages for all structures in the community. Appendix B describes the selection of these relationships in detail.

Direct damages for residential structres were established from the results of a study by Acres Ltd. in 1968 (1) and are shown below in Table 3.

Direct damages for commercial, industrial and institutional structures were derived from a report by Philips Planning and Engineering Ltd in 1976 (23) and are shown in Table 4. This report related damages to the area of the structure and depth of flooding relative to the first floor.

Table 3 Unit Stage-Damage Relationship (structure+content) for Frame or Brick Homes With Basements ($1979)

Stage Relative to First Floor (feet)	Direct Damage per Structure	
	Frame	Brick
-5	1330	1050
-4	1440	1105
-3	1605	1245
-2	1870	1345
-1	2195	1790
0	2775	2680
1	4715	5260
2	5875	7365
3	6076	7575
4	6540	7840
5	6900	8260
6	7120	8500
7	7280	8740

NOTE: The relationship was updated by a factor of 2.0 based on 'all goods' Consumer Price Index values of 90 and 180 for 1968 and 1979 respectively.

Table 4 Unit Stage-Damage Relationship (structure+content) for Commercial, Industrial, and Institutional Structures ($1979)

Stage Relative to First Floor (feet)	Direct Damage per Square Foot			
	Commercial		Industrial	Institutional
	No Basement	Basement		
0	0	2.9	0	0
1	1.65	3.39	0.74	0.59
2	2.16	3.90	1.77	0.88
3	2.45	4.20	2.94	1.10
4	2.82	4.57	3.83	1.47
5	3.12	4.86	4.87	1.92
6	3.48	5.22	5.87	2.43
7	3.85	5.59	6.77	2.47
8	4.22	5.96	7.65	3.53
9	4.70	6.76	8.69	4.04

NOTE: The relationship was updated by a factor of 1.5 based on 'all goods' Consumer Price Index values of 119 and 176 for 1974 and 1979 respectively

This method was used in the GRBWMS for industrial structures because of their large numbers in the floodplain (over 150). However, a more accurate method is to construct stage-damage curves for each industry that would reflect the wide range in types of industrial damages that could occur. Future studies should quantify industrial damages using this method (Ref. Appendix C).

Indirect Damages for residential, commercial, industrial and institutional structures were derived by Kate's in 1965 (10) as shown in Table 5.

Table 5 Indirect Damages as a ratio of Direct Damages

Damage Classification	Indirect damages as % of Direct Damages
Residential	15
Commercial	35
Industrial	45
Institutional	34

Public damages were assessed as 4% of total damages (direct + indirect) for all structures as recommended in the 1976 Philip's report previously mentioned (23).

A floodplain inventory of each community was taken from existing floodplain mapping with verification and updating by field observation and comparison with data provided by Philip's Planning and Engineering (Galt, Brantford, Dunnville); MacLaren's Ltd. (Bridgeport), J.D. Lee Engineering Ltd (Paris) and Triton Engineering Ltd. (Grand Valley). The inventory identified the type of structure, the elevation of the first occurrence of flooding (base opening), the first floor elevation and the presence of a basement.

For each one foot increase in stage at the reference cross section, the depth of flooding of each structure in the floodplain was established and the appropriate unit-stage-damage relationship was applied in order to calculate direct damages. The summing of all direct damages at a given stage, the addition of indirect damages and then calculation and addition of public damages produced the required stage-damage relationship.

5.0 FLOOD DAMAGES AND FLOOD DAMAGE REDUCTION IN THE GRAND RIVER BASIN - RESULTS

The total average annual damage ($1979) for the six major floodprone communities in the Grand River basin (Galt, Cambridge, New Hamburg, Brantford, Caledonia, Dunnville) is $989,000. This assumes the existing reservoir and dyking systems that include the Shand, Conestogo and Guelph Dams and represents a 58.7% reduction over the unregulated or natural average annual damages of $2,395,000.

The Montrose Dam proposals (both single and multi-purpose) would reduce average annual damages to between $426,000 and $453,000 for a 54% to 57% decrease over the existing system.

The Wallenstein (multi-purpose) and Salem (single purpose) Dams would each have similar effects on flood damages. Each would reduce average annual damages to $813,000 for an 18% decrease over the existing system. If both were built, they would reduce average annual damages to $538,000 for a 46% decrease over the existing system.

The St. Jacob's Dam (single purpose) would reduce average annual damages to $503,000 for a 49% reduction in damages over the existing system.

The combination of Wallenstein, Salem, St. Jacob's and Freeport Dams would reduce average annual damages to $390,000 for a 61% reduction in damages over the existing system.

The dams on the Nith River have no significant effect on average annual damages in the Grand River basin. The Nithburg Dam reduces flood damages of the three Nith River communities (New Hamburg, Plattsville and Ayr) from $34,500 to $13,100 but has no effect of flood damages at Paris and Brantford. The Ayr Dam reduces flood damages to zero in Ayr but has no effect on flood damages in New Hamburg or Plattsville and a minor effect on flood damages in Paris, Brantford and Caledonia.

Dyking and channelisation at Cambridge, Brantford and New Hamburg reduces average annual damages to $88,000 for a 91% reduction over the existing system. If the effect of Montrose Dam is added, average annual damages become $36,000 for a 96% reduction over the existing system.

The average annual damages under existing and proposed flood damage reduction projects for the six major floodprone communities are summarized in Table 6. For purposes of discussion, Cambridge average annual damages are made up of those of Galt and Preston; Hespeler damages are small in comparison. Grand Valley and Guelph were not included in the list of major floodprone areas since their damages would not be reduced by any of the proposed flood control reservoirs evaluated in this study.

A summary of existing flood damages for all fourteen floodprone communities is given in Table 7. This includes an inventory of the various types of structures located in the Regional floodplain as well as total damages for the 100 year and Regional flood events and total average annual damages.

Detailed analysis of the flood damages at Galt and Brantford indicate that over 60% of the damages at high flows are industrial while at the lower flows, residential damages predominate (Ref. Appendix B).

The next section describes the flow-damage-frequency relationship and calculation of resulting average annual damages for existing flood damage reduction projects for these fourteen communities.

Table 6 Average Annual Damages for 6 Major Floodprone Communities for Existing and Proposed Flood Damages Reduction Alternatives ($1979 x 1000)

Alternative System	Natural (no Reservoir)	Existing	Montrose (M)	Montrose (S)	St.Jacob's (S)	Wallenstein (M)	Salem (S)	Wallenstein(M) & Salem (S)
Location								
Cambridge	1,500	505	215	215	260	425	425	310
Paris	200	65	35	35	35	45	45	35
New Hamburg	25	25	25	25	25	25	25	25
Brantford	625	360	165	165	170	300	300	170
Caledonia	10	8	6	6	6	6	6	6
Dunnville	35	20	10	10	10	10	10	10
TOTAL	2,395	983	456	456	506	811	811	550
% Reduction Over Existing			54%	54%	49%	18%	18%	46%

Alternative System	Wallenstein (M) & Salem(S) & Freeport (S) & St.Jacobs (S)	Ayr (M)	Nithburg (M)	Dyking & Channel-isation	Dyking & Channel-isation & Montrose (S)
Location					
Cambridge	170	505	505	45	25
Paris	35	65	65	8	4
New Hamburg	25	25	10	0	0
Brantford	165	360	360	35	7
Caledonia	5.5	8	8	0	0
Dunnville	8	20	20	0	0
TOTAL	408.5	983	968	88	36
% Reduction Over Existing	61%	0%	3%	91%	96%

M - multi-purpose
S - single purpose

Table 7 Floodplain Inventory and Flood Damages for 14 Floodprone Communities

	Location	# Units in Regional Floodplain				Flow - Damage*				Avg. Annual Damages
						100/Year		REGIONAL		
		Residential	Commercial	Industrial	Inst.	Flow (cfs)	Damage ($1979)	Flow (cfs)	Damage ($1979)	
1.	Grand Valley	90	7	1	5	9,000	$ 98,300	26,700	$ 414,200	$ 28,000
2.	Elora	0	6	0	0	20,000	$ 20,000	22,000 +	$ 67,000	3,100
3.	Kitchener (Bridgeport)	80	9	5	1	46,000	$ 0	64,000	$ 0	1,000
4.	Guelph	554	29	16	5	6,800	$ 0	35,000	$ 8,000,000	30,000
5.	Cambridge (Hespeler)	0	0	15	0	6,900	$ 0	20,000 +	$ 640,000	2,000
6.	Cambridge (Preston)	59	13	6	3	6,800	$ 0	20,000 +	$ 3,000,000	15,000
7.	Cambridge (Galt)	290	127	30	56	55,000	$8,000,000	83,500	$33,600,000	490,000
8.	Paris	181	23	7	6	60,000	$1,500,000	107,000	$ 4,000,000	65,000
9.	New Hamburg	95	21	3	3	17,700	$ 220,000	30,000 +	$ 700,000	25,000
10.	Plattsville	73	8	2	6	17,800	$ 150,000	28,000 +	$ 590,000	2,000
11.	Ayr	17	3	1	3	15,200	$ 50,000	26,000 +	$ 135,000	10,000
12.	Brantford	2543	63	66	24	62,300	$ 900,000	120,000	$67,000,000	360,000
13.	Caledonia	99	13	0	6	57,700	$ 15,000	130,000	$ 624,000	8,000
14.	Dunnville	668	29	3	22	54,700	$ 45,000	143,000	$ 3,200,000	20,000

* Direct Structural and Content Damages + Indirect Damages + Public Damages
\+ Regional flow estimates from Grand River Basin Water Management Study

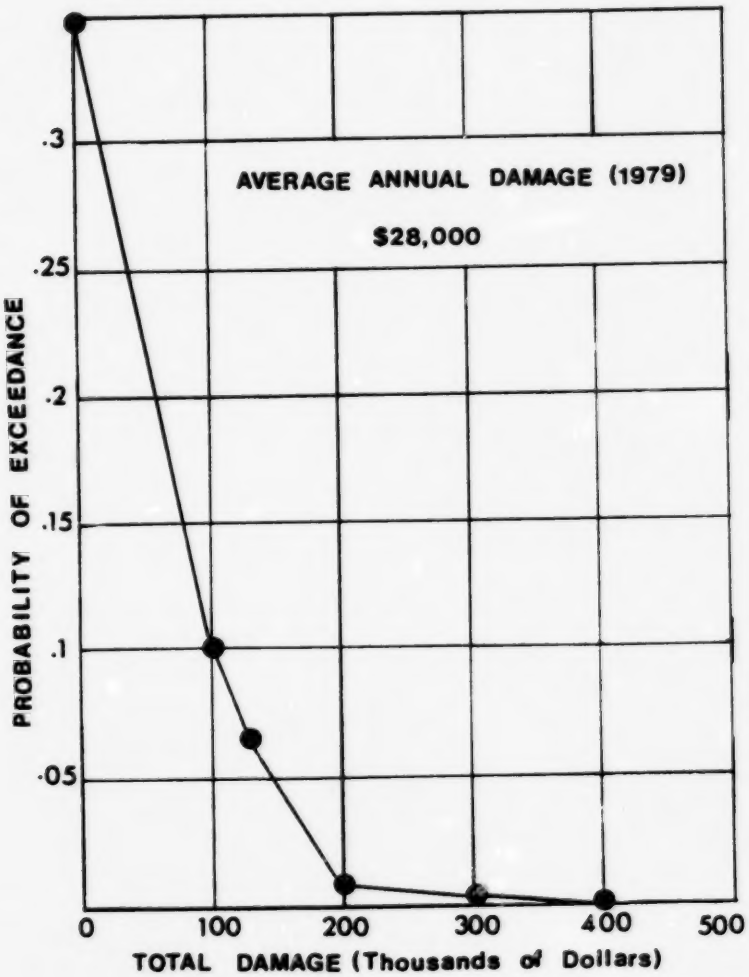
5.1 Grand Valley

The total average annual damages for Grand Valley are $28,000 as shown in Figures 5 and 6 and Table 8 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively).

The Grand River floodplain at Grand Valley contains 90 residential, 7 commercial, 1 industrial and 5 institutional structures and has no existing flood control measures. The average annual damage reflects the effects of frequent flooding but no large damages. The last major spring freshet flood event was in 1974 but there has been major flooding due to ice jams since then.

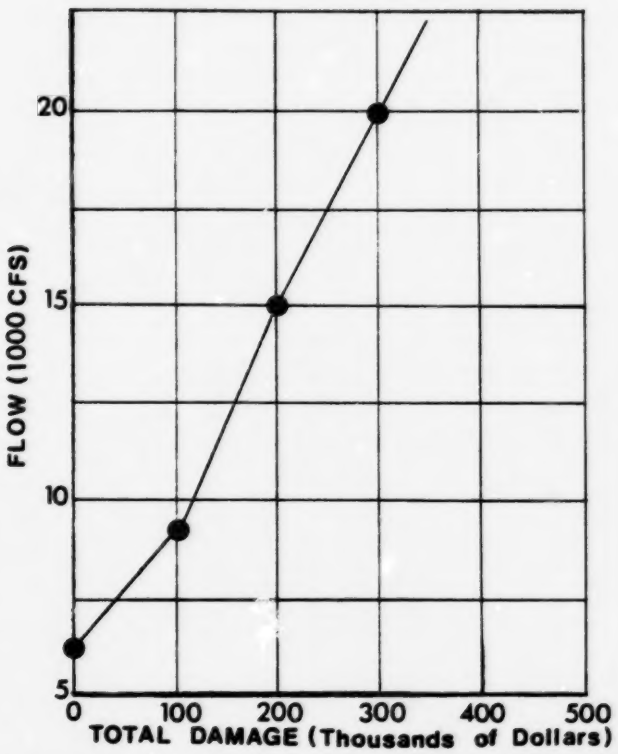
Most of the flow and inventory information was drawn from a report prepared for the Grand River Conservation Authority by Triton Engineering Ltd. in 1978 (28).

FIGURE 5



GRAND VALLEY FREQUENCY - DAMAGE CURVE

FIGURE 6



GRAND VALLEY FLOW-DAMAGE CURVE

Table 8 Average Annual Damages for Existing Conditions (1979) GRAND VALLEY

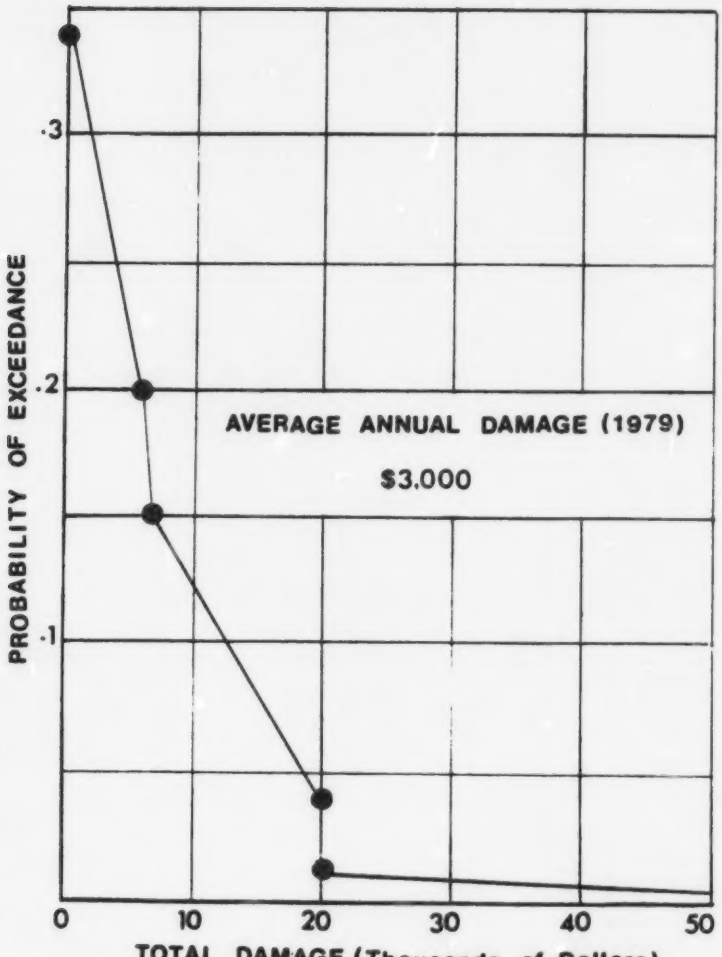
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
6	0		0.3500		
		98,300		0.2300	22,700
9	98,300		0.1000		
		21,700		0.0850	1,845
19	120,000		0.0700		
		78,000		0.0380	2,964
15	198,000		0.0060		
		102,000		0.0035	357
20	300,000		0.0010		
		110,000		0.0007	77
25	410,000		0.0003		
		Total Average Annual Damages			$27,943

5.2 Elora

The total average annual damages for Elora are $3000 as shown in Figures 7 and 8 and Table 9 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively).

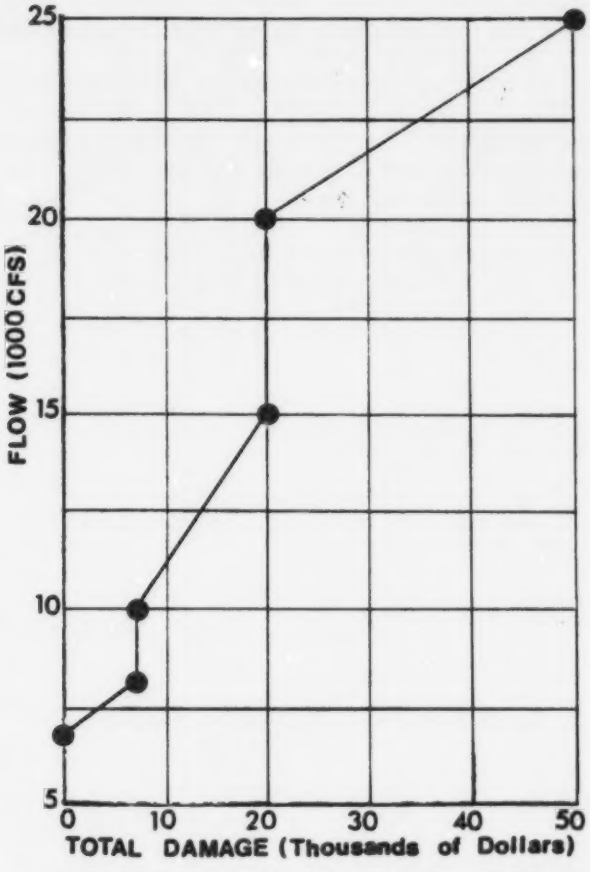
The Grand River floodplain at Elora contains 6 commercial structures and flooding is controlled by the Shand Dam. The average annual damages are relatively small and reflect frequent flooding with minor damages and for this reason were not included in the total of major damages in the Grand River Basin.

FIGURE 7



ELORA FREQUENCY - DAMAGE CURVE

FIGURE 8



ELORA FLOW-DAMAGE CURVE

Table 9 Average Annual Damages for Existing Conditions (1979) ELORA

FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
7	0		.3400		
		6,000		.2700	1,620
8	6,000		.2000		
		0		.1750	0
10	6,000		.1500		
		14,000		.0950	1,330
15	20,000		.0400		
		0		.0250	0
20	20,000		.0100		
		30,000		.0065	195
25	50,000		.0030		
		Total average Annual Damages			$3,145

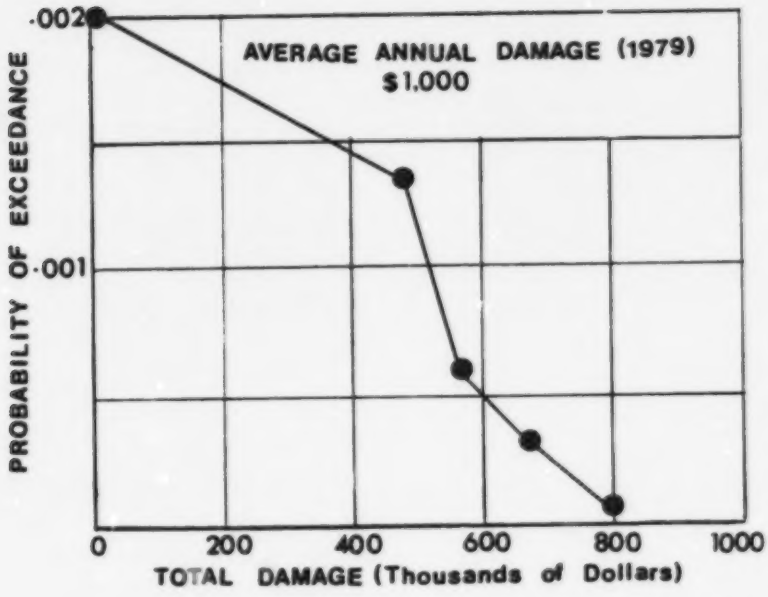
5.3 Kitchener (Bridgeport)

The total average annual damages for Bridgeport are less than $1000 as shown in Figures 9 and 10 and Table 10 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively).

The Grand River floodplain at Bridgeport contains 80 residential, 9 commercial, 5 industrial and 1 institutional structure. It is protected to the Regional Flow by a dyking system built in 1979 and by flow regulation from the Shand and Conestogo Dams. The average annual damage reflects this existing protection.

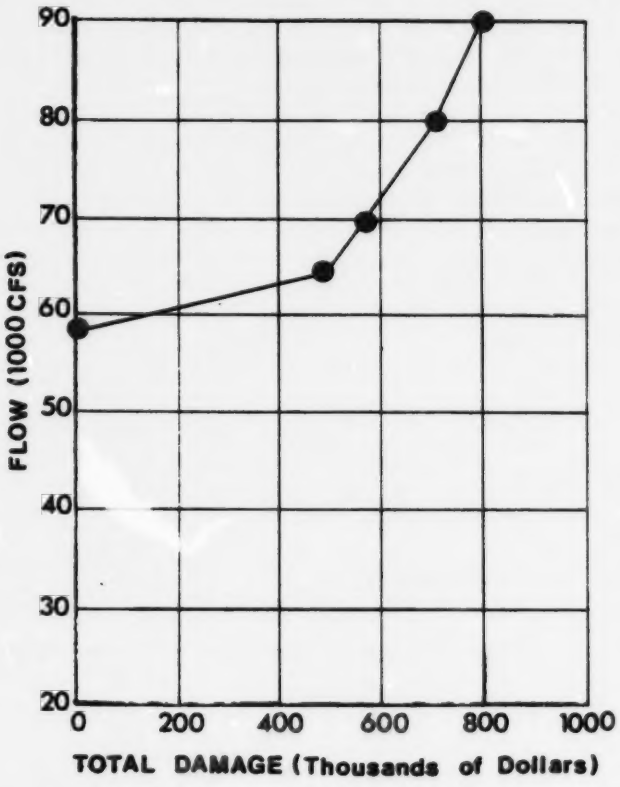
The Regional Flow and much of the floodplain inventory was drawn from a report prepared for the GRCA by MacLarens Ltd. in 1978 (17).

FIGURE 9



BRIDGEPORT FREQUENCY-DAMAGE CURVE

FIGURE 10



BRIDGEPORT FLOW-DAMAGE CURVE

Table 10 Average Annual Damages for Existing Conditions (1979) BRIDGEPORT

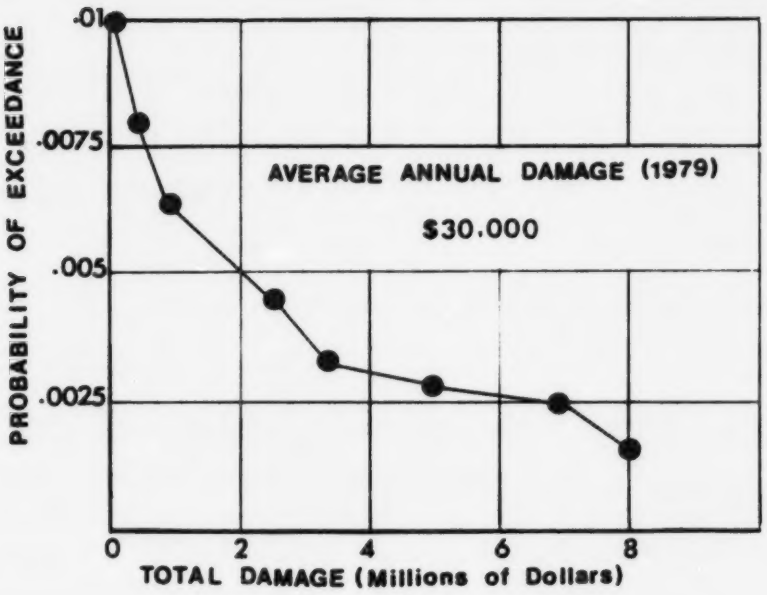
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
60	0		.0020		
		500,000		.0013	850
65	500,000		.0013		
		80,000		.0010	80
70	580,000		.0007		
		120,000		.0005	60
80	700,000		.0003		
		100,000		.0002	20
90	800,000		.0001		
		Total Average Annual Damages			$1,010

5.4 Guelph

The total average annual damages for Guelph are $30,000 as shown in Figures 11 and 12 and Table 11 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively). The Regional Flow at Guelph should be reviewed; it is possible that estimated average annual damages could be significantly lower than those shown (Ref. Appendix B).

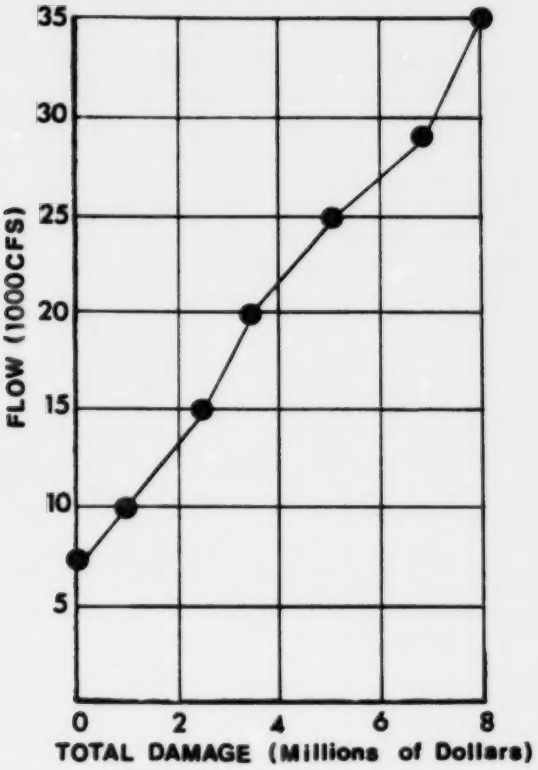
The Speed and Eramosa River floodplains at Guelph contain 554 residential, 29 commercial, 16 industrial and 5 institutional structures. Flooding is reduced by the Guelph dam on the Speed River and various dyking schemes such as the Silver Creek Parkway. The average annual damage reflects this present level of protection and reflects the fact that although the city is presently protected from major flooding up to the 100 year flow, larger floods would cause significant damage.

FIGURE 11



GUELPH FREQUENCY-DAMAGE CURVE

FIGURE 12



GUELPH FLOW-DAMAGE CURVE

Table 11 Average Annual Damages for Existing Conditions (1979) GUELPH

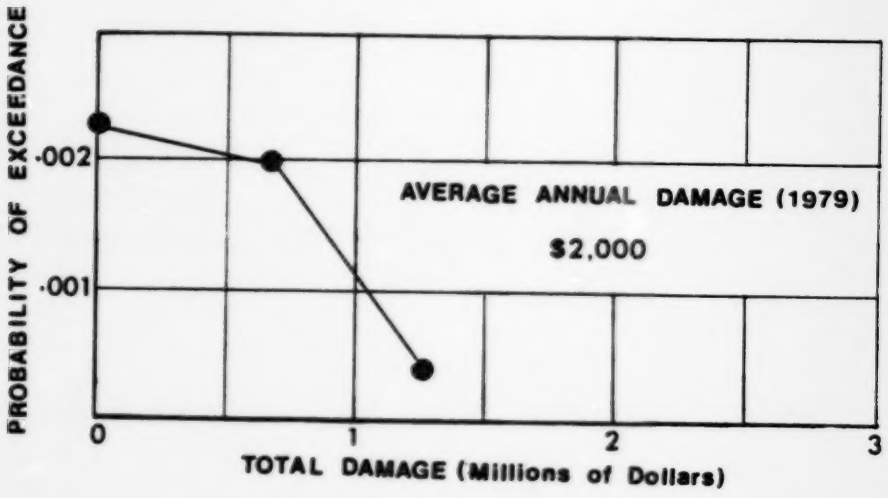
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
7	0		.0100		
		340,000		.00900	3,060
8	340,000		.0080		
		460,000		.00725	3,335
10	800,000		.0065		
		1,400,000		.00550	7,700
15	2,200,000		.0045		
		1,200,000		.00400	4,800
20	3,400,000		.0035		
		1,400,000		.00325	4,550
25	4,800,000		.0030		
		2,200,000		.00275	6,050
30	7,000,000		.0025		
		1,000,000		.00225	2,250
35	8,000,000		.0020		
		Total Average Annual Damages			$31,745

..5 Cambridge (Hespeler)

The total average annual damages for Hespeler are $2,000 as shown in Figures 13 and 14 and Table 12 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively).

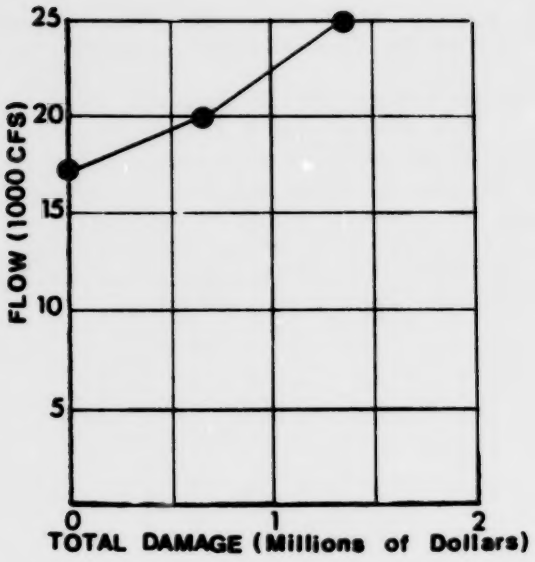
The Speed River floodplain at Hespeler contains 16 industrial structures. It is protected by dykes built in 1972 that overtop at 18,000 cfs. and by flow regulation of the Guelph reservoir. In a previous study by Kilborn Engineering Ltd. (11), the Regional Flood had been established at 25,000 cfs with no flow regulation. Additional studies using HEC-5 show that the regional flow would be reduced to 20,000 cfs. by the Guelph reservoir. Further study is required to confirm the regional flow.

FIGURE 13



HESPELER FREQUENCY-DAMAGE CURVE

FIGURE 14



HESPELER FLOW-DAMAGE CURVE

Table 12 Average Annual Damages for Existing Conditions (1979) HESPELER

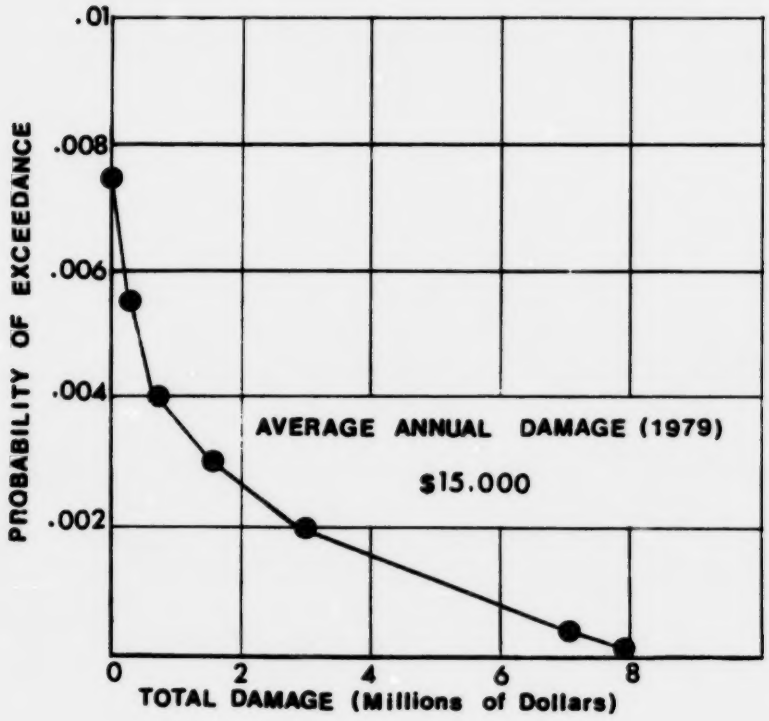
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
18	0		.0025		
		640,000		.00215	1,375
20	640,000		.0020		
		660,000		.00120	792
25	1,300,000		.0004		
		Total Average Annual Damages			$2,167

5.6 Cambridge (Preston)

The total average annual damages for Preston are $15,000 as shown in Figures 15 and 16 and Table 13 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively).

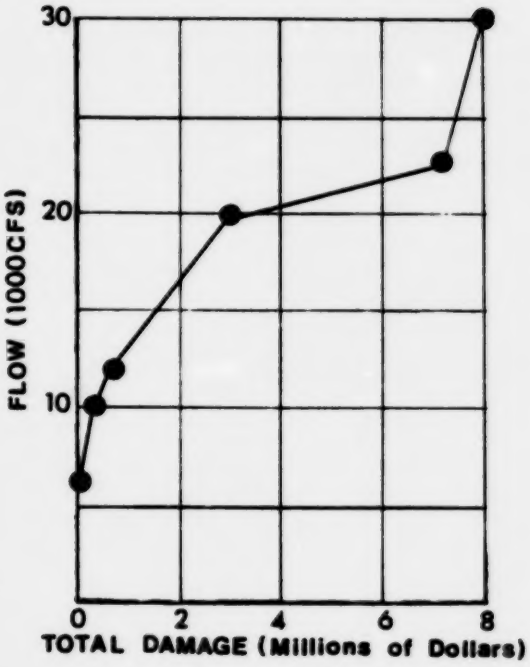
The Speed River floodplain at Preston contains 60 residential, 13 commercial, 6 industrial and 3 institutional structures. Flood flows are presently affected by the Guelph reservoir so that there is no flooding up to the 100 year event. The average annual damage reflects large damages that would occur at extreme events.The Regional Flow (regulated) was assumed to be 20,000 cfs. (as discussed in section 5.5) which includes the effect of the Guelph reservoir. The regional flow should be verified by further study.

FIGURE 15



PRESTON FREQUENCY-DAMAGE CURVE

FIGURE 16



PRESTON FLOW-DAMAGE CURVE

Table 13 Average Annual Damages for Existing Conditions (1979) PRESTON

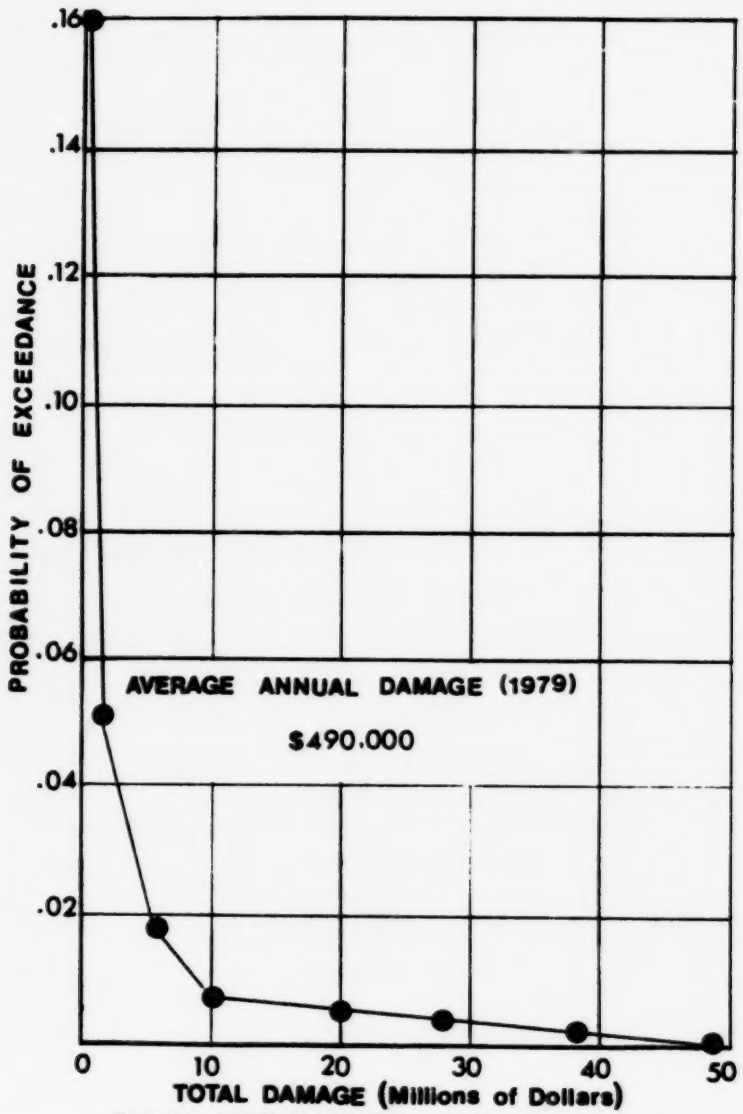
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
6	0		.0100		
		4,000		.00875	35
8	4,000		.0075		
		106,000		.00650	689
10	110,000		.0055		
		290,000		.09475	1,376
12	400,000		.0040		
		1,000,000		.00350	3,500
15	1,400,000		.0030		
		1,600,000		.00250	4,000
20	3,000,000		.0020		
		4,000,000		.00125	5,000
25	7,000,000		.0005		
		1,000,000		.00030	3,000
30	8,000,000		.0001		
			Total Average Annual Damages		$14,900

5.7 Cambridge (Galt)

The total average annual damages for Galt are $490,00 as shown in Figures 17 and 18 and Table 14 (the frequency-damage curve, flow-damage curve and flow-frequency-damage relationship respectively).

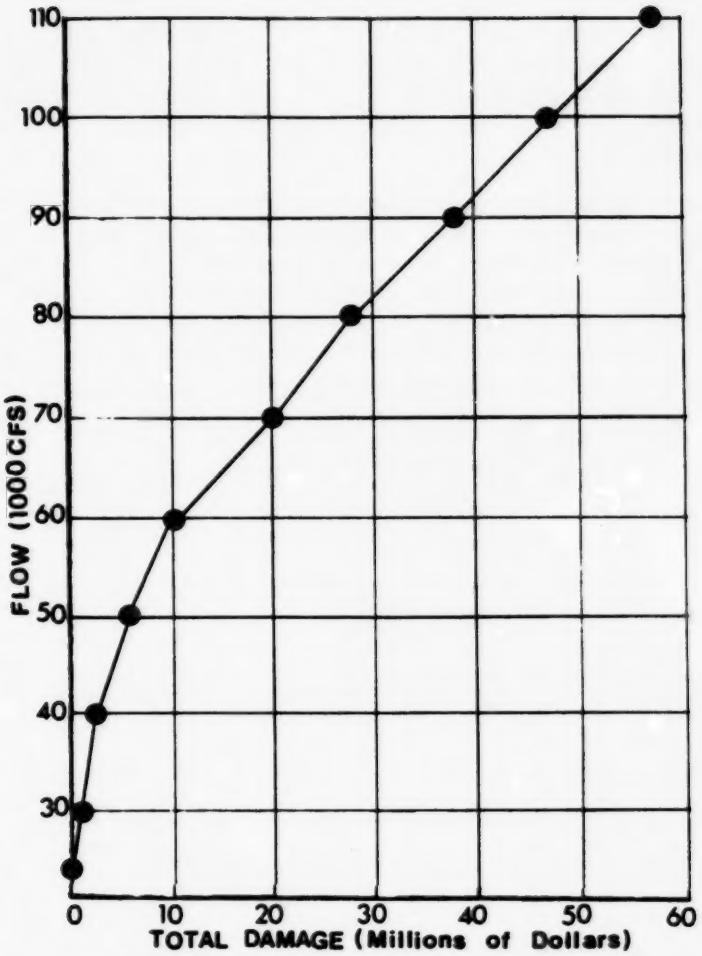
The Grand River floodplain at Galt contains 290 residential units, 127 commercial units, 30 industries and 56 institutional buildings and is presently protected to the regional flow above Parkhill Road Bridge with some floodwall protection downstream of this. The damages in figure 6 reflect this existing protection and suggest large damages even at the more frequent flow events.

FIGURE 17



GALT FREQUENCY-DAMAGE CURVE

FIGURE 18



GALT FLOW-DAMAGE CURVE

Table 14 Average Annual Damages for Existing Conditions (1979) GALT

FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
30	0		.16000		
		1,660,000		.10750	178,450
40	1,660,000		.05500		
		3,750,000		.03650	136,875
50	5,610,000		.01800		
		4,790,000		.01250	59,875
60	10,400,000		.00700		
		9,045,000		.00565	51,104
70	19,445,000		.00430		
		9,045,000		.00290	26,231
80	28,490,000		.00250		
		10,200,000		.00200	20,400
90	38,690,000		.00150		
		8,810,000		.00120	10,570
100	47,500,00		.00090		
		8,500,000		.00070	5,950
110	56,000		.00050		
		Total Average Annual Damages			$489,455

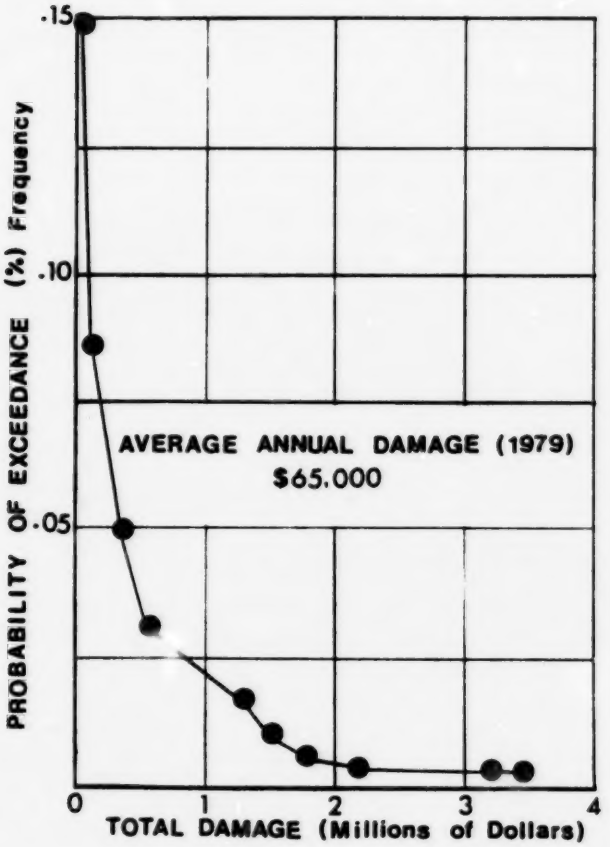
5.8 Paris

The total average annual damages for Paris are $65,000 as shown in Figures 19 and 20 and Table 15 (the frequency-damage curve, flow-damage curve and flow-frequency-damage relationship respectively).

The Grand and Nith River floodplain at Paris contains 181 residential units, 23 commercial units, 7 industries and 6 institutional buildings and is presently protected on the East bank by a dyking system built to protect to the 100 year flood. The West bank, the commercial district, has no protection. The damages in figure 6 reflect the existing protection and suggest a potential for high damages from flooding by the more extreme flood flows.

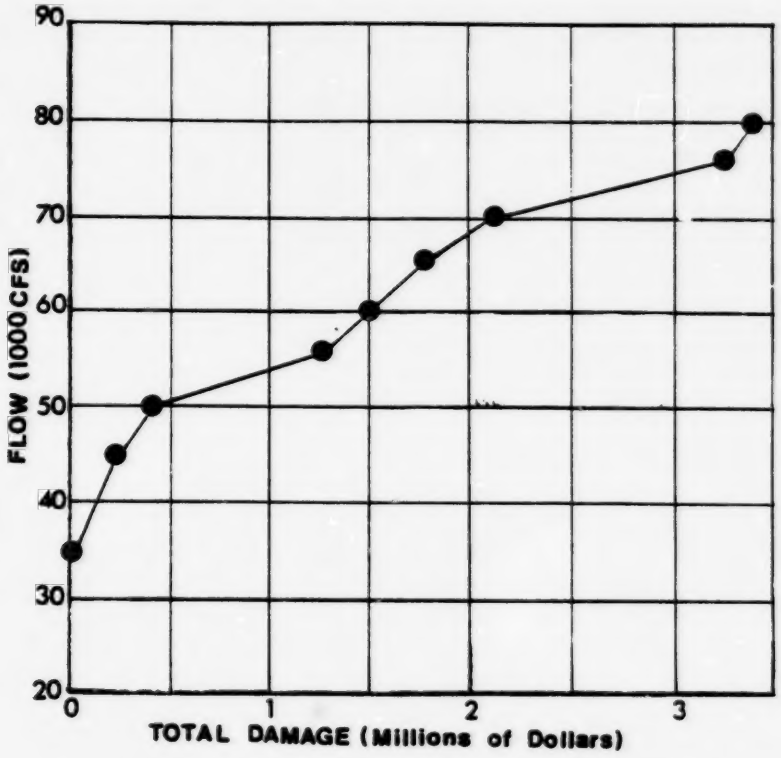
Much of the floodplain inventory was drawn from a report prepared for the GRCA by J.D. Lee Ltd. in 1978 (14).

FIGURE 19



PARIS FREQUENCY-DAMAGE CURVE

FIGURE 20



PARIS FLOW-DAMAGE CURVE

Table 15 Average Annual Damages for Existing Conditions (1979) PARIS

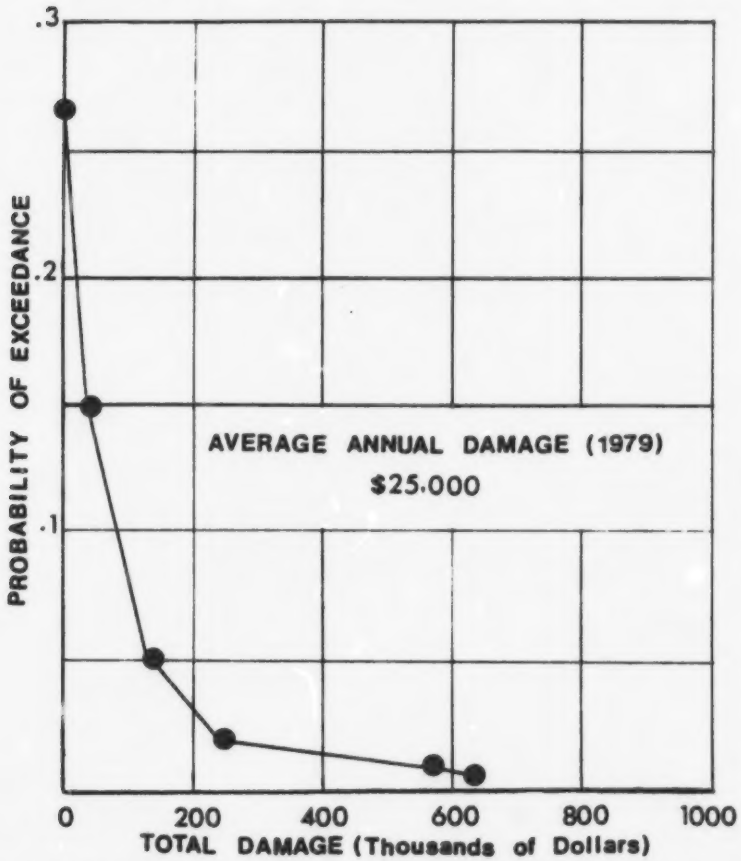
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD
30	0		.2400		
		11,000		.2000	2,200
35	11,000		.1500		
		77,000		.1200	9,240
40	88,000		.0900		
		118,000		.0700	8,260
50	375,000		.0300		
		866,000		.0240	20,784
55	1,241,000		.0180		
		259,000		.0140	3,625
60	1,500,000		.0080		
		300,000		.0090	2,700
65	1,800,000		.0080		
		320,000		.0075	2,400
70	2,120,000		.0070		
		1,113,000		.0065	7,235
75	3,233,000		.0060		
		167,000		.0050	918
80	3,400,000		.0050		
		Total Average Annual Damages			$64,000

5.9 New Hamburg

The total average annual damages for New hamburg are $25,000 as shown in Figure 21 and 22 and Table 16 (the frequency-damage curve,flow-damage curve and flow-frequency-damage relationship respectively).

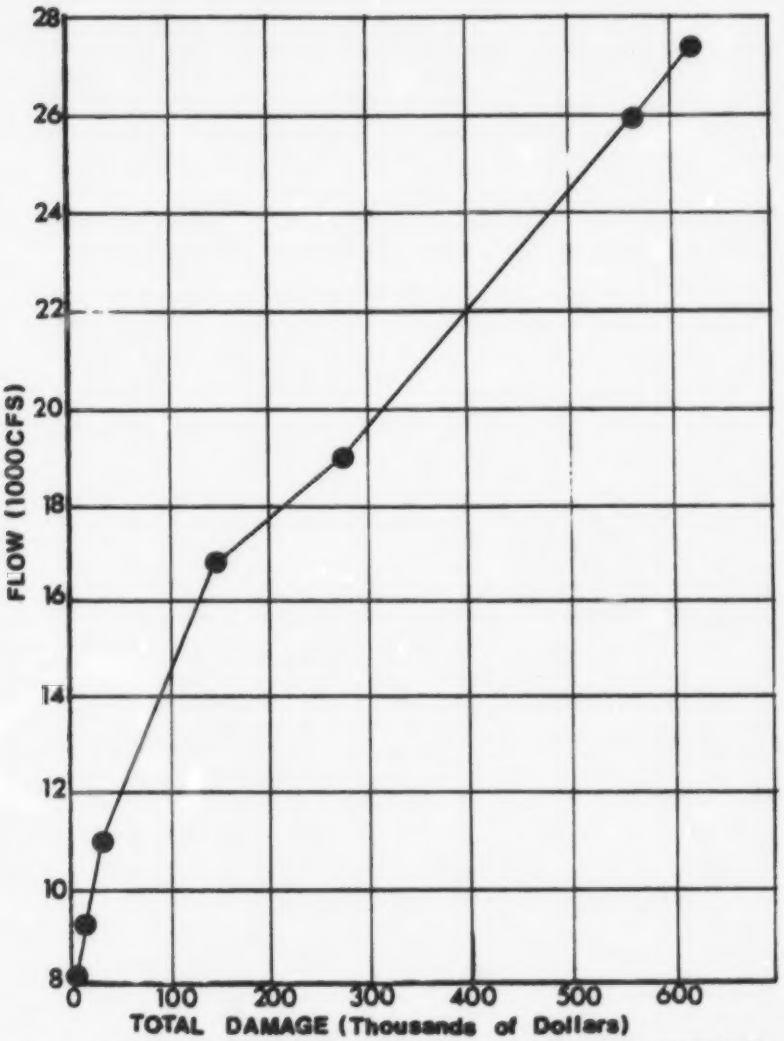
The Nith River floodplain at New Hamburg contains 95 residential units, 21 commercial units, 3 industries and 3 institutional buildings and is presently protected to the 5 year flow by a low dyke. The damages in figure 6 reflect this existing protection and indicate frequent flooding of the residential area with potential for large commercial damage at less frequent flood flows.

FIGURE 21



NEW HAMBURG FREQUENCY-DAMAGE CURVE

FIGURE 22



NEW HAMBURG FLOW-DAMAGE CURVE

Table 16 Average Annual Damages for Existing Conditions (1979) NEW HAMBURG

FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
8	0		.3500		
		4,700		.3100	1,457
9	4,700		.2700		
		21,500		.2100	4,515
11	26,200		.1500		
		113,800		.1000	11,380
15	140,000		.0500		
		137,700		.0330	4,544
19	278,300		.0160		
		289,100		.0097	2,800
26	567,400		.0035		
		48,467		.0030	145
27	615,867		.0025		
		Total Average Annual Damages			$24,841

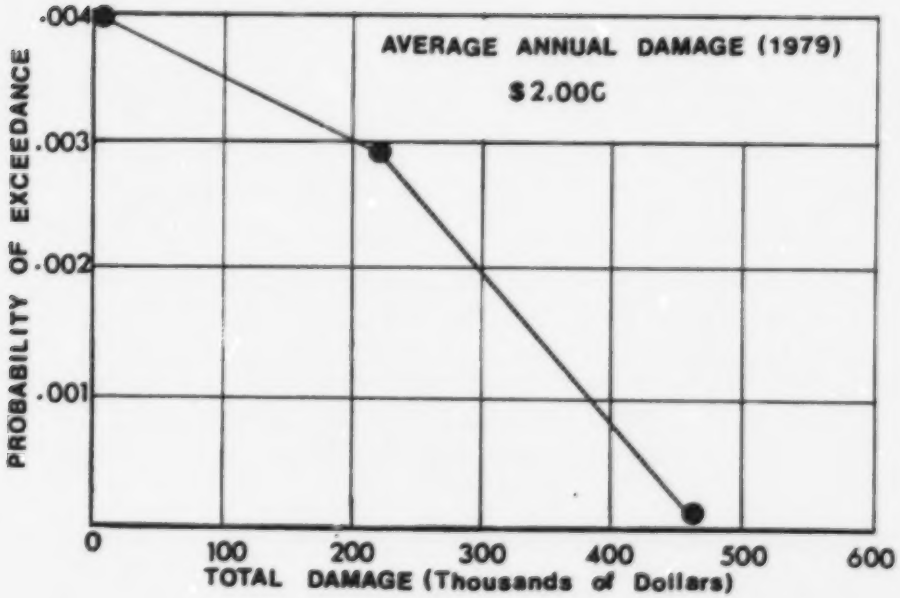
5.10 Plattsville

The total average annual damages for Plattsville are $2,000 as shown in Figures 23 and 24 and Table 17 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively).

The Nith River floodplain at Plattsville contains 73 residential, 8 commercial, 2 industrial and 6 institutional structures and is presently protected to at least the 100 year event by a small dyke.

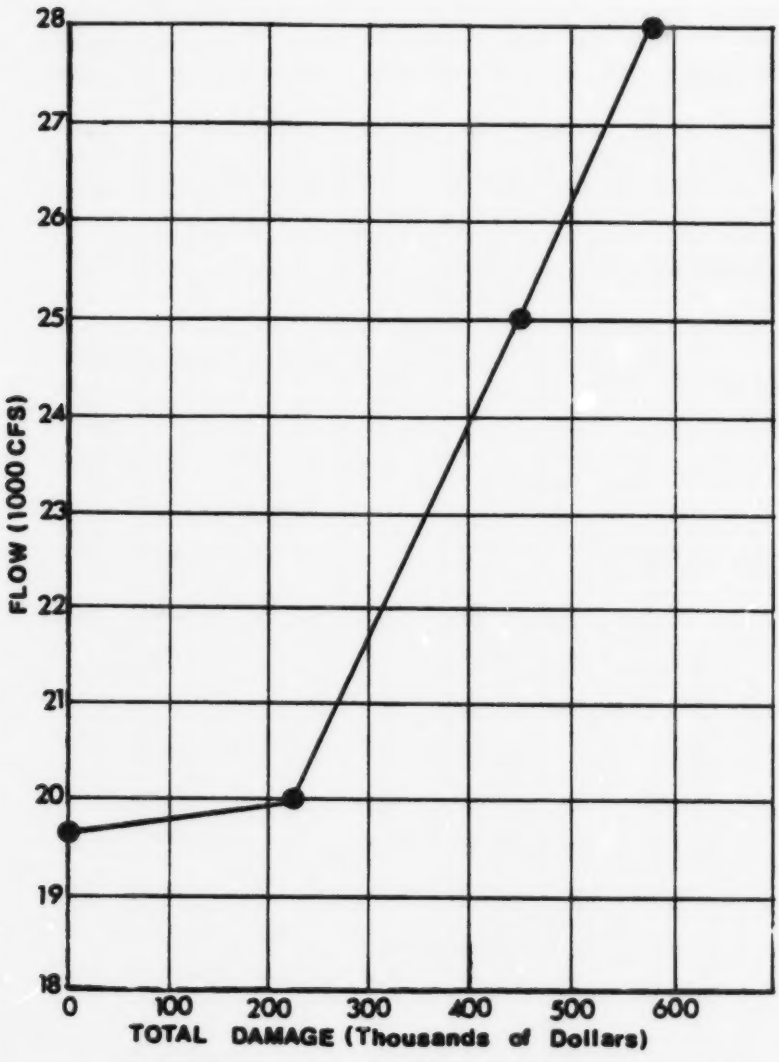
The average annual damage reflects this existing protection and indicates a potential for high damages at less frequent flood events.

FIGURE 23



PLATTSVILLE FREQUENCY-DAMAGE CURVE

FIGURE 24



PLATTSVILLE FLOW-DAMAGE CURVE

Table 17 Average Annual Damages for Existing Conditions (1979) PLATTSVILLE

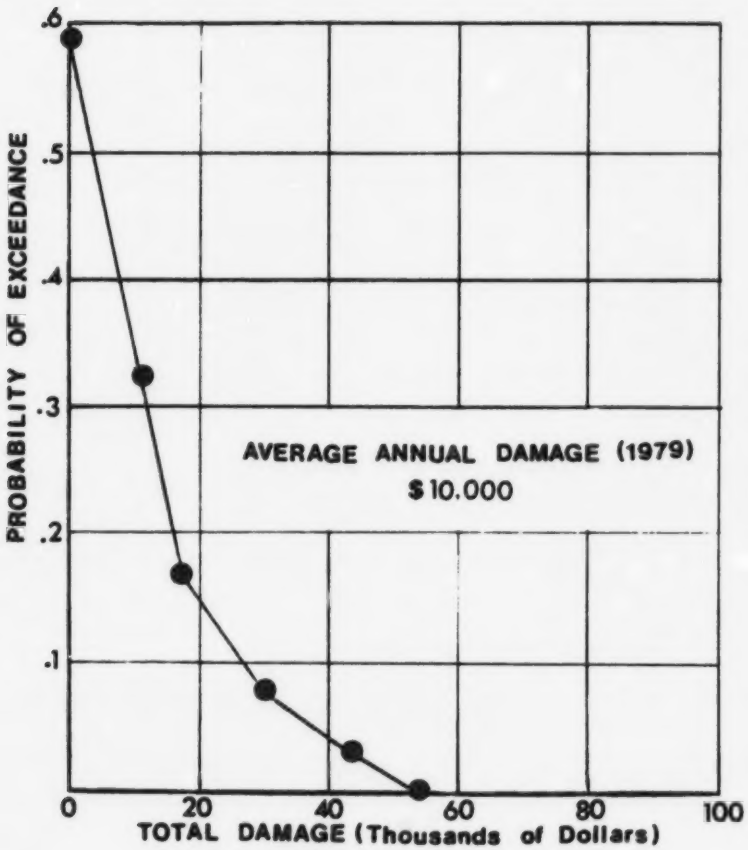
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
19.5	0		.0040		
		220,000		.00350	770
20	220,000		.0065		
		225,000		.00475	1,069
25	445,000		.0030		
		145,000		.00250	363
28	590,000		.0020		
		Total Average Annual Damages			$2,202

5.11 Ayr

The total average annual damages for Ayr are $10,000 as shown in Figures 25 and 26 and Table 18 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively).

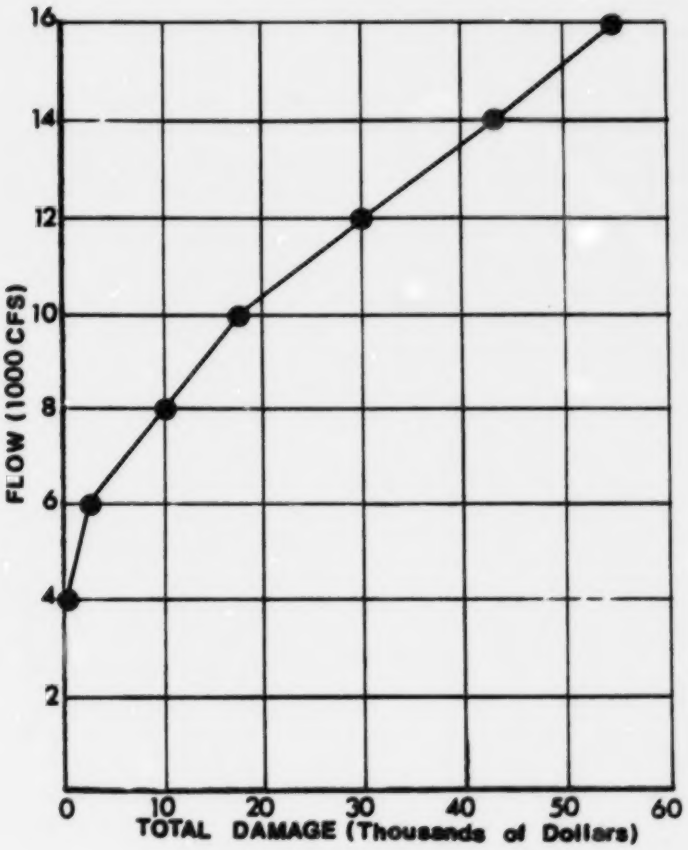
The Nith River floodplain at Ayr contains 17 residential, 3 commercial, 1 industrial and 3 institutional structures. There is no flood protection and the average annual damage figure represents frequent, minor flooding of the non-residential structures with a potential for flooding of the residential structures at less frequent flood events.

FIGURE 25



AYR FREQUENCY-DAMAGE CURVE

FIGURE 26



AYR FLOW-DAMAGE CURVE

Table 18 Average Annual Damages for Existing Conditions (1979) AYR

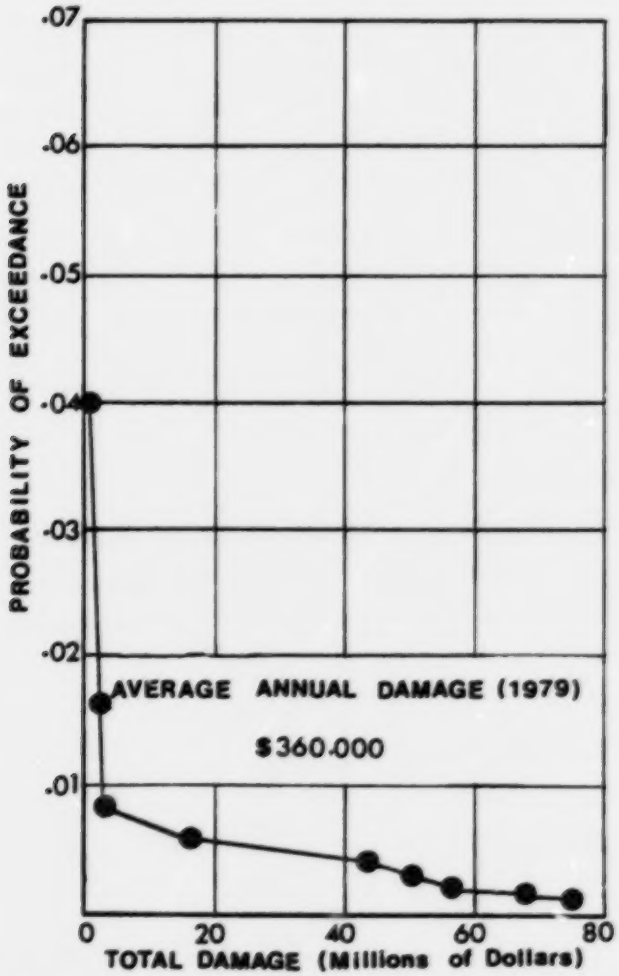
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
6	0		.6000		
		9,810		.4700	4,611
8	9,810		.3400		
		7,630		.2450	1,869
10	17,440		.1500		
		13,080		.1050	1,831
12	30,520		.0600		
		13,080		.0400	523
14	43,600		.0200		
		10,900		.0145	158
16	54,500		.0090		
		Total Average Annual Damages			$8,972

5.12 Brantford

The total average annual damages for Brantford are $360,00 as shown in Figures 27 and 28 and Table 19 (the frequency-damage curve, flow-damage curve and flow-frequency-damage relationship respectively).

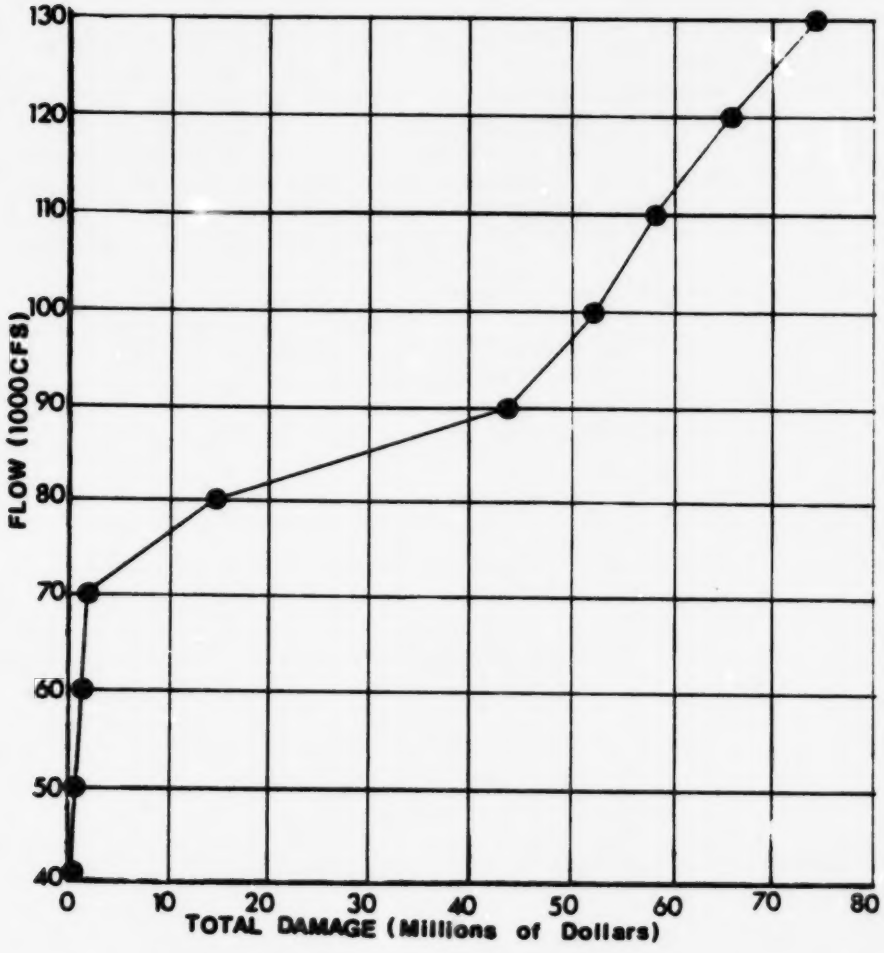
The Grand River floodplain at Brantford contains 2543 residential units, 63 commercial units, 66 industries and 24 institutional buildings and is presently protected to the regional flow in the Holmwood area. West Brantford is protected to the 100 year event by a dyking system and River Road acts as a dyke by protecting land adjacent to it to the 50 year event before it is rounded. The damages in figure 6 reflect this existing protection and indicate minor flooding at frequent flood levels with a potential for major damages at the less frequent flood flows.These damages do not reflect a phase of the dyking system completed in 1982.

FIGURE 27



BRANTFORD FREQUENCY-DAMAGE CURVE

FIGURE 28



BRANTFORD FLOW-DAMAGE CURVE

Table 19 Average Annual Damages for Existing Conditions (1979) BRANTFORD

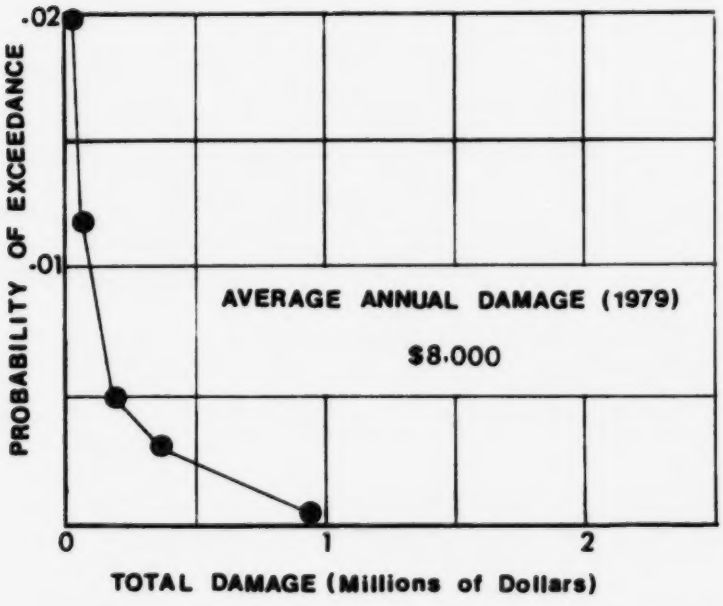
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES
40	0		.1000		
		300,000		.07000	21,000
50	300,000		.0400		
		700,000		.02700	18,900
60	1,000,000		.0140		
		0		.01100	0
70	1,000,000		.0080		
		14,500,000		.00700	101,500
80	15,500,000		.0060		
		28,000,000		.00500	140,000
90	43,500,000		.0040		
		8,00,000		.00350	28,000
100	51,500,000		.0030		
		7,000,000		.00275	19,250
110	58,500,000		.0025		
		8,500,000		.00225	19,125
120	67,000,000		.0020		
		6,000,000		.00175	10,500
130	73,000,000		.0015		
		Total Average Annual Damages			$358,275

5.13 Caledonia

The total average annual damages for Caledonia are $8,000 as shown in Figures 29 and 30 and Table 20 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively). This is based an a Regional Flow of 130,000 cfs as established in a study in 1974 by Philip's Planning and Engineering Ltd. (22). However, the average annual damage could range as low as $4,000 : a Grand River Basin Water Management Study preliminary study suggests the Regional Flow could be 90,000 cfs. Further study is suggested.

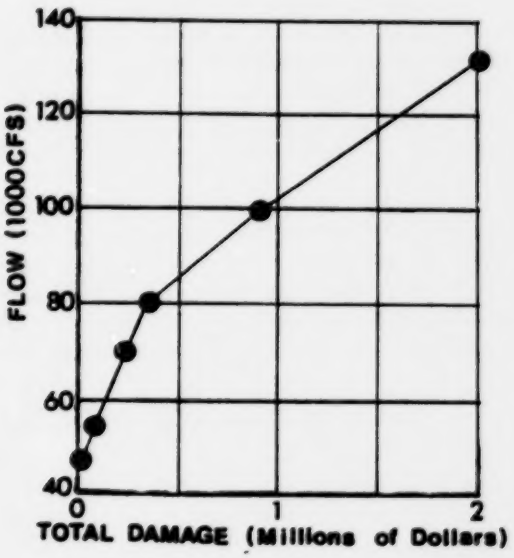
The Grand River floodplain at Caledonia contains 99 residential, 13 commercial and 6 institutional structures. The existing north bank road affords protection to a large residential area to at least the 100 year event. The average annual damage reflects this existing protection and indicates some frequent minor flooding with a potential for large commercial and residential damages at less frequent events.

FIGURE 29



CALEDONIA FREQUENCY-DAMAGE CURVE

FIGURE 30



CALEDONIA FLOW-DAMAGE CURVE

Table 20 Average Annual Damages for Existing Conditions (1979) CALEDONIA

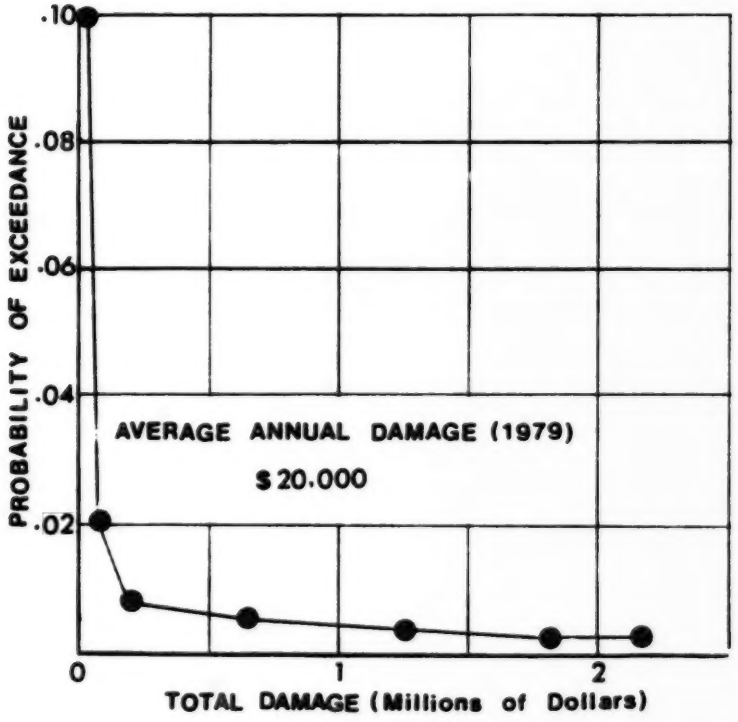
FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
50	0		.0200		
		13,000		.01625	211
55	13,000		.0125		
		117,000		.00950	1,111
70	130,000		.0065		
		182,000		.00575	1,047
80	312,000		.0050		
		624,000		.00425	2,652
100	936,000		.0035		
		1,064,000		.00258	2,745
130	2,000,000		.0020		
		Total Average Annual Damages			$7,576

5.14 Dunnville

The total average annual damages for Dunnville are $20,000 as shown in Figures 31 and 32 and Table 21 (the frequency-damage curve, flow-damage curve and flow-frequency-damage table respectively). This is based on a Regional Flow of 143,000 cfs. established in 1978 (26). However, preliminary Grand River Basin Water Management Study results suggest the regional is 110,000 cfs. Further study is recommended.

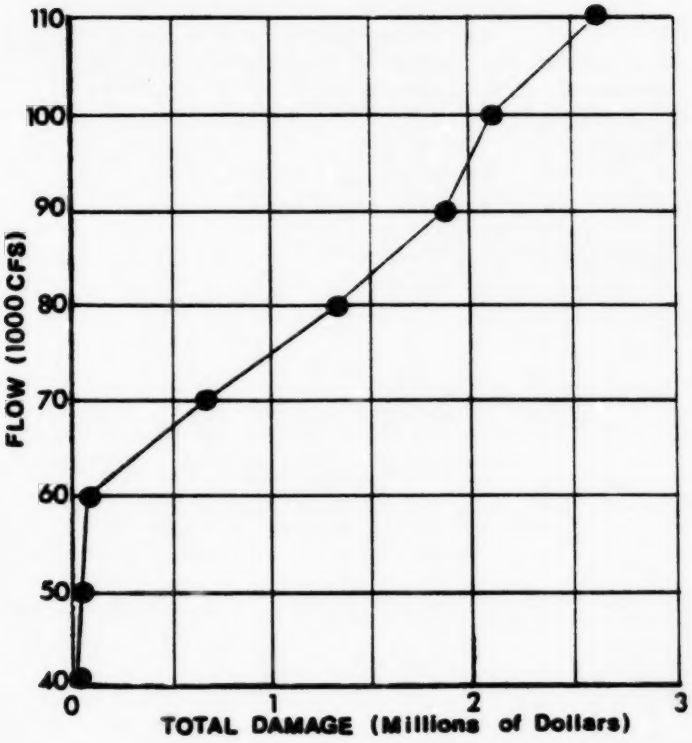
The Grand River floodplain at Dunnville contains 668 residential, 29 commercial, 3 industrial and 22 institutional structures that are presently protected to greater than the 50 year event by hwy #53 that acts as a dyke. The average annual damage reflects this existing protection and indicates frequent minor flooding with a potential for large residential damages at less frequent flood flows.

FIGURE 31



DUNNVILLE FREQUENCY-DAMAGE CURVE

FIGURE 32



DUNNVILLE FLOW-DAMAGE CURVE

Table 21 Average Annual Damages for Existing Conditions (1979) DUNNVILLE

FLOW (CFS X 1000)	TOTAL DAMAGE ($1979)	DAMAGE OF INTERVAL	FREQUENCY	AVG. FREQ. OF INTRV.	AVG. ANNUAL DAMAGES (AAD)
30	0		.1800		
		17,000		.1200	2,040
40	17,000		.0600		
		36,000		.0400	1,440
50	170,000		.0200		
		117,000		.0150	1,850
60	650,000		.0090		
		480,000		.0080	3,840
70	650,000		.0070		
		650,000		.0062	4,030
80	1,300,000		.0035		
		500,000		.0050	2,500
90	1,800,000		.0045		
		300,000		.0043	1,290
100	2,100,000		.0040		
		500,000		.0035	1,750
110	2,600,000		.0030		
		300,000		.0029	870
120	2,900,000		.0028		
		Total Average Annual Damages			$19,610

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APPENDIX A - Regulated Flow-Frequency Curves

For the communities subject to flow regulation by upstream reservoirs, existing or proposed, the regulated flow frequency curve was used in calculating flood damages. The regulated flow frequency curve will depend upon the amount of reservoir flood storage available at the beginning of the flood. A family of regulated flow frequency curves for each downstream community could be produced for different flood storage capacities (Ref. Fig. A-2). To determine the effect of upstream reservoir storage upon flood frequency curves at major damage centres, a brief study was carried out to determine the effect the Belwood and Conestogo Reservoirs would have upon the flood frequency curves at Cambridge (Galt), the first major damage centre encountered downstream of the two reservoirs.

Inflow flood hydrographs for different flood events were routed through the two reservoirs to Cambridge using the Hec 5 reservoir simulation model. Inflow hydrographs were simulated for 5, 10, 25, 50 and 100 year return periods. For different return periods, Figure A-1 shows how the peak flows at Cambridge (Galt) are affected by varying amounts of available flood storage capacity in the Belwood and Conestogo reservoirs.

Using Figure A-2, flood frequency curves were derived for varying amounts of available reservoir flood storage. Above twenty percent of available reservoir flood storage, the frequency curves are the same. Twenty percent of available flood storage capacity corresponds to April 1 operating conditions as defined by the existing GRCA reservoir operation policy. April 1 operating conditions specify that twenty percent of the total flood storage be made available for flood control. March 1 existing operating conditions specify ninety percent of available flood storage be made available. Because of the insensitivity to available flood storage, a single reservoir storage capacity was selected to use in routing all inflows up to the 100 year event through the system. This resulted in a single regulated flow frequency at Cambridge (Galt) and all downstream Grand River damage centres.

Figure A-1 Flood Peak Reduction at Cambridge (Galt) for Various Reservoir Storage Capacities (Belwood and Conestogo reservoirs)

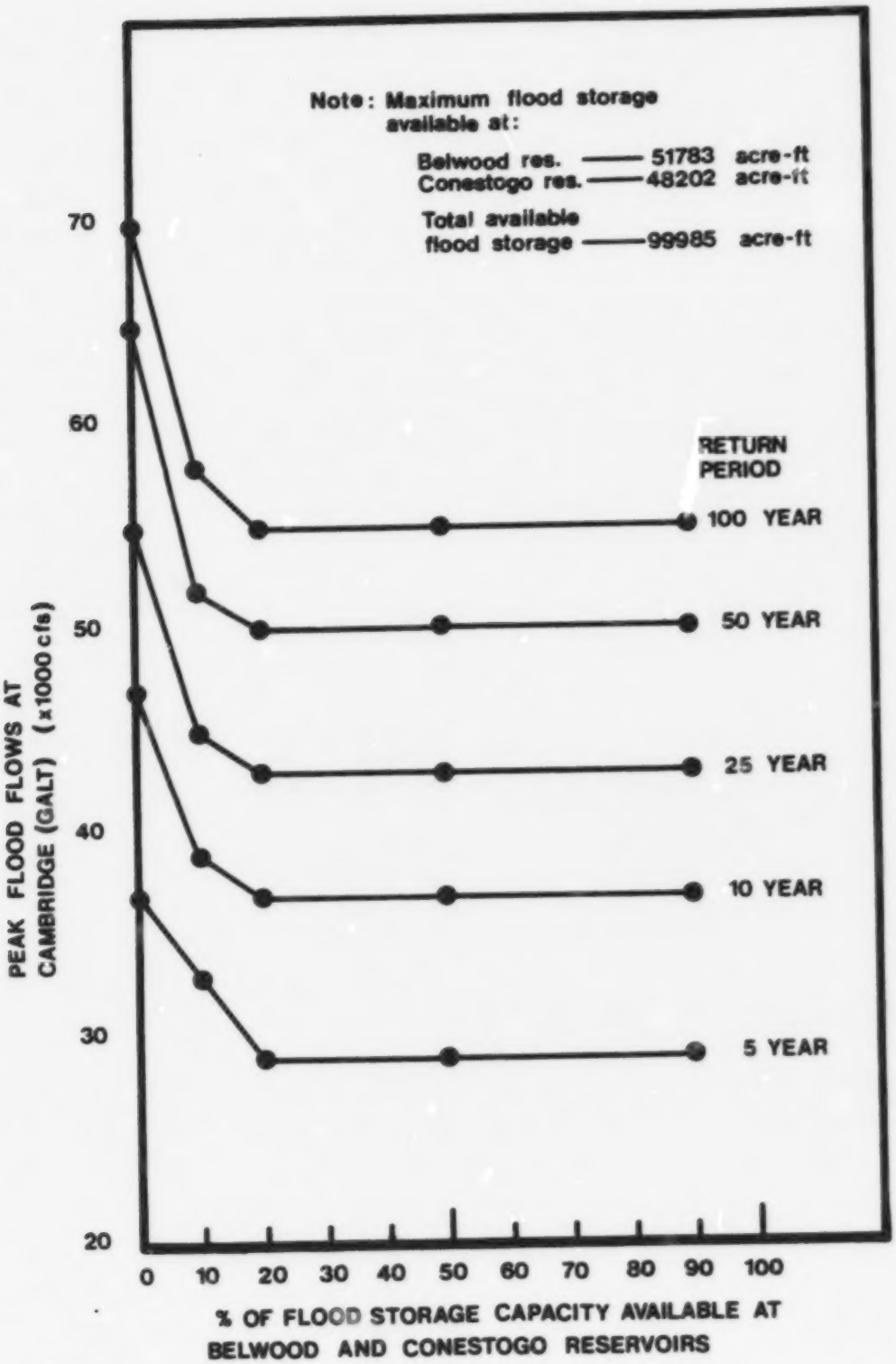
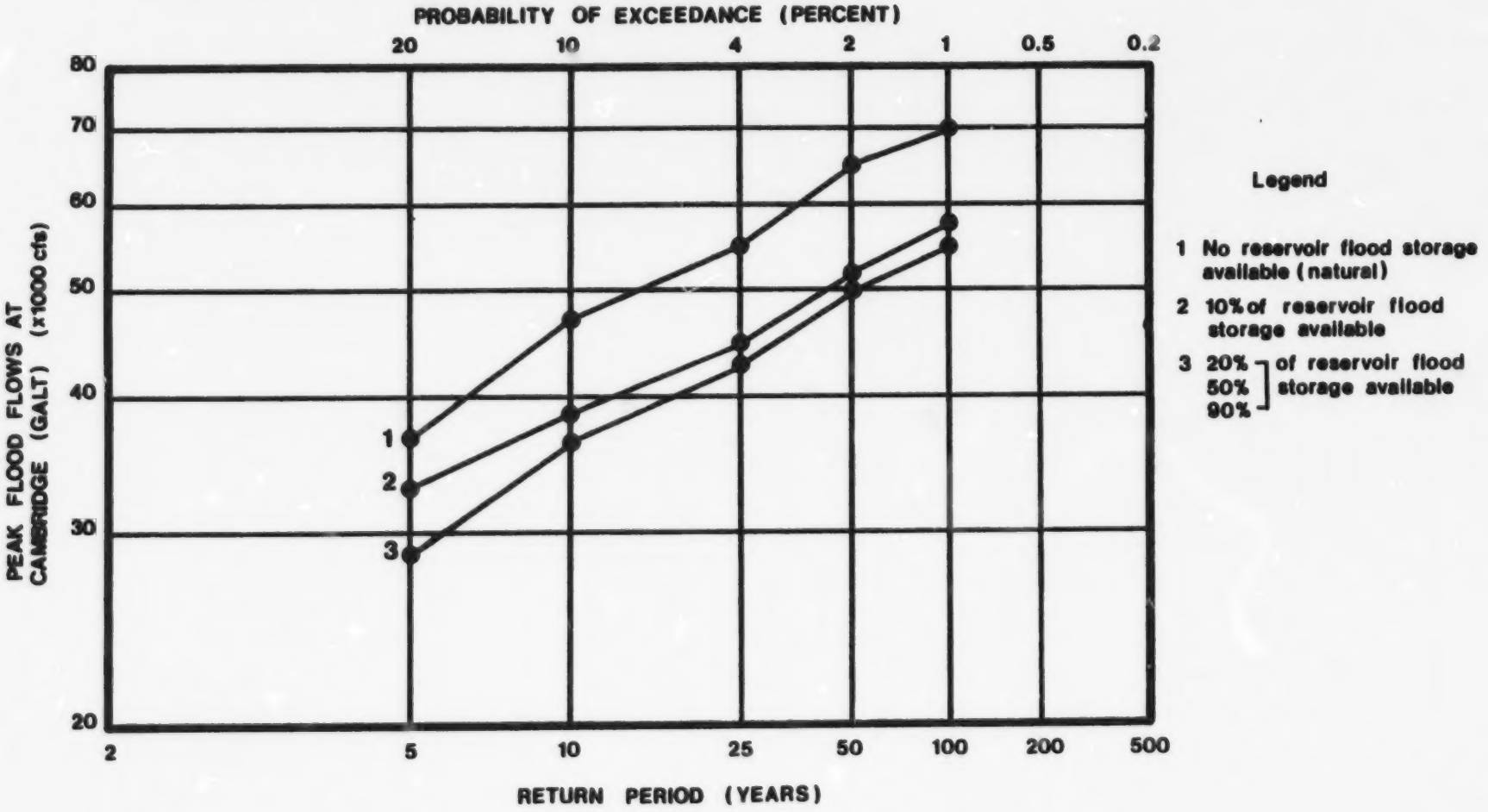


Figure A-2 Flood Frequency Curves at Cambridge (Galt) for Various Flood Storage Capacities (Belwood and Conestogo reservoirs).



APPENDIX B - Regional Flows

The return period for a Regional Flood in the Grand River Basin was assumed to be the same as the return period for the Regional Flood of Etobicoke Creek over which Hurricane Hazel was centered in 1954. The flow for the Summerville gauge for this event is 13,700 cfs (3) (see Table B-2) which has roughly a 500 year return period (15) (see Figure B-1).

The following Table shows the effect on average annual damages of selecting different return periods for the Regional Flow.

Table B-1 Average Annual Damages at Galt and Brantford for Different Return Periods of the Regional Flow

Location	Return Period (Years)		
	200	500	1000
Brantford	$280,000	360,000	510,000
Galt	$460,000	490,000	595,000

The Regional Flows used in the flood damage analysis of the various floodprone urban areas are shown in Table B-3. The table also shows the Grand River Basin Water Management Studies' preliminary estimates of these Regional Flows which should be verified.

Table B-2 Summary of Estimated Maximum Flows for Metro Toronto Watersheds (from Reference #3)

Location	Drainage Area	Probable Maximum		Storm "Hazel" centred		Observed Maximum	
	sq. mi.	c.f.s.	c.s.m.	c.f.s.	c.s.m.	c.f.s.	c.s.m.
ETOBICOKE CREEK							
Summerville (gauge)	63.8	29,300	460	13,700	215	8,000	125
Brampton (channel)	27					5,000	185
Snelgrove (dam site)	19	9,600	505	4,330	227		
HUMBER RIVER MAIN BRANCH							
Weston (gauge)	308.5	96,700	314	50,000	157	45,600	148
Upper Woodbridge (gauge)	116	42,000	360	19,000	163	16,000	138
Nashville (dam site)	107	41,000	385	18,500	172		
Bolton (town)	75	35,000	470	15,000	200	4,500	60
Bolton (dam site)	74	34,780	470	14,000	200		
WEST BRANCH							
Thistletown (gauge)	79	42,600	540	22,200	281	18,000?	227?
Claireville (dam site)	72	38,800	540	20,200	281		
Ebenezer (dam site)	53	31,300	590	16,500	312		
EAST BRANCH							
Nobleton (town)	49	20,100	410	10,300	209	8,000?	163?
Lower E. Br. (dam site)	53	21,700	410	11,000	209		
King Creek (dam site)	51	21,000	410	10,700	209		

Figure B-1 Peak Flow Recurrence Interval for Etobicoke Creek at Summerville (from Reference #15)

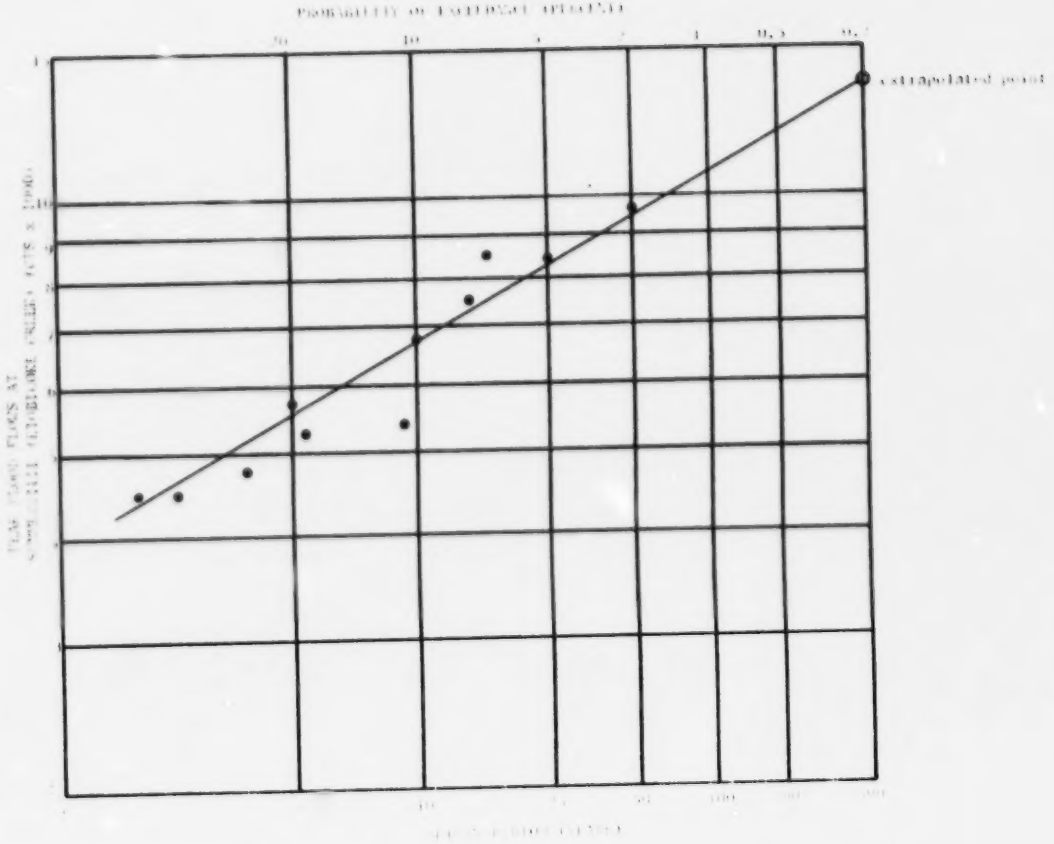


Table B-3 Regional Flows used in Flood Damage Analysis

Flood Damage Centre	Regional Flood used in Estimating Average Annual Damages		Regional Flood Calculated by Basin Study*
	Flow	Source	Flow
Grand Valley	26,700	(27)	**
Elora	22,000	GRBWMS	22,000
Kitchener (Bridgeport)	64,000	(17)	71,600
Guelph	35,000	(12)	19,700
Cambridge (Hespeler)	20,000	(11)	22,400
Cambridge (Preston)	20,000	(11)	22,400
Cambridge (Galt)	83,500	(22)	82,600
Paris	107,00	(14)	92,100
New Hamburg	30,000	GRBWMS	***
Plattsville	28,000	GRBWMS	***
Ayr	26,000	GRBWMS	***
Brantford	120,000	(24)	95,100
Caledonia	130,000	(23)	86,800
Dunnville	143,000	(25)	80,900

* Using equivalent circle drainage area

** The Basin Study started modelling the system at the Shand Dam

*** These results are based on a Regional Storm centered for Brantford using the exact drainage area above Brantford.

APPENDIX C - Unit Stage-Damage Relationships

The severity of direct flood damages is affected by primary factors (depth of flooding and value of structure and contents) and secondary factors (duration of flood, flood water velocity, sediment content, flood warning and individual/group reaction and degree of floodproofing).

Various consulting firms and government agencies have developed unit stage-damage relationships that take into account primary flood damage factors. Secondary factors add a degree of complexity that is not usually considered in flood damage studies except to say that "average" conditions exist (1).

1. Residential Unit Stage-damage Relationships

Two approaches may be used in the estimation of residential flood damages. The historical method uses records of past flood depths and related observed damages; the synthetic method attempts to quantify damages using structural type, probable contents, and estimated repair and depreciated replacement costs.

Two different residential unit stage-damage relationships were evaluated for this study:

a) Synthetic relationships developed in 1968 by Acres's Ltd. (1) based on field surveys of house structure and content in Cambridge-Galt. The study produced structural and content damage tables for 5 different grades of brick and frame homes. For the Grand River Basin Water Management Study an average grade was assumed for homes in the floodplain and the structural and content tables were combined to yield one table of total direct damage versus depth of flooding. In addition, basement damages were increased by $1000 based on a review of flood damages in Bridgeport in 1974 (17) (see Table C-1).

b) Historical curves developed in 1970 by the U.S. Federal Insurance Administration (FIA) based on observed damages from the U.S. Army Corps of Engineers with updates from FIA insurance claims as data becomes available. The FIA produces structural and content damage tables that gives damages as a per cent of the market value of the house and its contents (7,30,32). For the Grand River Basin Water Management Study a total direct damage table was produced by assuming content value as 30% of the market value of the house (see Table C-2).

Table C-1 Unit Stage-Damage Relationship (structure+content) for Frame or Brick Homes with Basements ($1979) (modified ACRES)

Stage Relative to First Floor (feet)	Direct Damage per Structure	
	Frame	Brick
-5	1330	1050
-4	1440	1105
-3	1605	1245
-2	1870	1345
-1	2195	1790
0	2775	2680
1	4715	5260
2	5875	7365
3	6076	7575
4	6540	7840
5	6900	8260
6	7120	8500
7	7280	8740

Table C-2 FIA Depth-Damage Relationship (structure+content) for Residential Structures

Depth Relative to First Floor (feet)	Damage as % Market Value			
	(1)*	(2)	(3)	(4)
-4	0	0	0	0
-3	0	1	0	4
-2	0	6	0	6
-1	0	9	0	8
0	10	12	7	9
1	14	21	10	14
2	26	25	17	20
3	38	29	22	27
4	42	35	26	35
5	47	41	31	42
6	54	47	34	45
7	58	52	38	49

NOTE: Content value was assumed to be 30% of structural market value

* (1) one storey, no basement
(2) one storey, with basement
(3) two storey, no basement
(4) two storey, with basement

Flood damages for Bridgeport and Paris were calculated, using the two different tables, for flood elevations reached in the May 1974 flood. These damages were compared with actual values reported by the Grand River Disaster Relief Fund (see Table C-3). Results suggest that the Acre's relationship provides closest agreement with observed residential damages and that they should be used to derive residential, direct flood damamges in the Grand River basin.

A subsequent study by Marshall, Macklin, Monoghan Ltd.(20) on flood damages on the Thames River in southern Ontario combined the Acre's and FIA relationships to produce a unit stage-damage table that has significantly higher damages at flood depths greater than 2 feet (see Table C-4). These results appear interesting and the reader is directed to that report for details.

2. **Commercial, Industrial and Institutional** Unit Stage-Damage Relationships

The relationships used in the Grand River Basin Water Management Study to estimate direct flood damages for these classifications were developed by Philips Planning and Engineering Ltd. (PPE) in 1976 (24). They were based on damages resulting from the 1974 flood in Cambridge -Galt and used a curve fitting method with the available data (depths of flooding and corresponding damage) to produce the required curve.

Ideally, industrial unit stage-damage relationships should be developed on an site by site basis due to each industries' unique structural and inventory features. Unfortunately, due to insufficient data and time, this was not possible in the Basin Study. As table C-5 and Table C-6 indicate, industrial damages are the major contributor to flood damages at higher flows in the Grand River Basin.

The PPE industrial relationships were based on damages found in the records of the Grand River Disaster Relief Fund. Payments were made from the fund to commercial and industrial organisations which could be described as small businesses (under 30 employees). However, in Brantford and Galt there are several industries which would not fall into this class and whose damages would not be correctly reflected by the PPE tables. A look at the direct damages actually incurred by one of these sites in 1974 and comparison with damages predicted by the table established a multiplier of 10 in order to correctly assess damages for this class of industry. This multiplier was then used for damages at all levels of flooding.

Table C-3 Comparison of Observed 1974 Residential Flood Damages at Bridgeport and Paris with Estimated Damages ($1979)

Location	Damages (x$1000)		
	Estimated		Observed
	FIA	ACRES	
Bridgeport	414	232	220
Paris	117	96	53

Table C-4 Residential Unit Stage-Damage Relationship: Glen Gowan Dam Study (from Ref. 20)

Two storey house with basement.
Average damage in 1979 dollars.

Depth Relative to first floor	Type of Residential Structure					
	AB	BB	CB	AW	BW	CW
-7.5	2059	570	156	1783	1110	822
-7	1573	570	289	2274	1110	827
-6	2981	612	594	2690	1198	940
-5	3248	851	768	2934	1289	1051
-4	3539	1184	992	3200	1386	1167
-3	3856	1648	1283	3490	1491	1296
-2	4202	2292	1658	3807	1604	1439
-1	5603	3056	2210	5076	2137	1919
0	6403	3438	2487	5711	2404	2159
1	9806	5347	3868	8884	3739	3358
2	14008	7639	5526	12691	5342	4797
3	18911	10313	7460	17133	7212	6476
4	24514	13368	9671	22209	9349	8395
5	29417	16042	11605	26651	11218	10074
6	31518	17188	12433	28555	12019	10793
7	34320	18716	14539	31093	13088	11753

Table C-5 Total Flood Damages at Galt - %Contribution by Residential, Commercial, Industrial, Institutional and Public Damages ($1979)

FLOW (x1000cfs)	30	40	50	60	70	80	90
TOTAL DAMAGE (millions)	0	1.7	5.6	10.4	19.5	28.5	38.7
DAMAGE CLASS	% of Total Damages						
Residential	0	12	6	7	5	4	4
Commercial	0	41	49	32	23	20	14
Industrial	0	29	32	50	63	68	74
Institutional	0	14	9	7	5	4	4
Public	0	4	4	4	4	4	4

Table C-6 Total Flood Damages at Brantford - %Contribution by Residential, Commercial, Industrial, Institutional and Public Damages ($1979)

FLOW (x1000cfs)	40	60	80	100	120
TOTAL DAMAGE (millions)	0	1.0	15.5	51.5	67.0
DAMAGE CLASS	% of Total Damages				
Residential	0	88	23	25	25
Commercial	0	0	3	2	2
Industrial	0	0	67	65	65
Institutional	0	8	3	4	4
Public	0	4	4	4	4

POOR

QUALITY

ORIGINAL